(12)

AD

AD-E401 611

TECHNICAL REPORT ARAED-TR-86040

AD-A175 401

BALLISTIC SIMULATOR SHOCK TESTING OF ARMAMENT COMPONENTS

ANDERS J. KARLSEN

DECEMBER 1986

US ARMY
ARMAMENT
MUNITIONS &
CHEMICAL COMMAND
ARMAMENT RDE CENTER

U. S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
ARMAMENT ENGINEERING DIRECTORATE
DOVER, NEW JERSEY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report ARAED-TR-86040	2. GOVT ACCESSION NO.: AD-A175 401
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): BALLISTIC SIMULATOR SHOCK TESTING OF ARMAMENT COMPONENTS	5. TYPE OF REPORT & PERIOD COVERED: Final Report, Mar 84 - Jun 86
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Anders J. Karlsen	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: ARDEC, AED, Commodity Evaluation Div (SMCAR-AEC-TEE), Dover, NJ 07801-5001	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: ARDEC, IMD, STINFO Div (SMCAR-MSI), Dover, NJ 07801-5001	12. REPORT DATE: December 1986
	13. NUMBER OF PAGES: 61
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Director, U.S. Army Materials Technology Laboratory, ATTN: SLCMT-MSI-QA, Watertown, MA 02172-2719	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES This project has been accomplished as part of the U.S. Army's Manufacturing Testing Technology Program, which has for its objective the timely establishment of testing techniques, procedures, and prototype equipment (in mechanical, chemical, and nondestructive testing) to ensure efficient inspection methods of material/materiel procured and maintained by AMC.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ballistic simulator	Digital memory module
Gas gun	Laboratory simulation
Gunfire shock	MTT-Test equipment
Ballistic shock	In-bore data recorder
High-g shock	Memory telemeter

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this project, ARDEC completed the development and testing of a 155-mm gas gun ballistic simulation system initially designed and constructed by Frankford Arsenal. The goal of the project was to provide a cost effective alternate to live explosive gun firings through simulation of high-g impulse shock in a laboratory environment. The two tasks were: (1) development of a lightweight digital memory module (DMM) that would operate in high-g ballistic shock environment, and (2) establishment and documentation of the characteristics of (cont)

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (cont)

the gas gun simulator with the DMM.

A multichannel DMM using basic digital design, implemented by state-of-the-art electronic components, was successfully developed. The newly developed DMM was used to acquire setback and tangential acceleration data for more than 50 test firings.

The performance characteristics and range (acceleration amplitude and duration) of the simulator as a function of extremes in metering hole patterns was established.

The acceleration amplitudes and durations generated by the simulator can be varied within its operational range to provide good simulations of gun fire shock parameters which are not otherwise reproducible in a laboratory facility. The order of magnitude increase in duration over diaphragm-type air guns, plus its spin capability, makes the simulator useful for a variety of applications in which conventional diaphragm-type air guns are unsatisfactory.

SUMMARY

The objective of the project was to make available the gas gun simulator as a cost-effective simulation of live explosive gun firings in a laboratory environment. This was accomplished by development of a multichannel digital memory module (DMM) and utilization of it in a series of test firings to measure the simulator's characteristics.

The general characteristics of the acceleration time history generated by the simulator have been established. The shape of the acceleration time curve is similar to gun fire shock: the acceleration rises approximately sinusoidally to its peak value, followed by an exponential decay, a constant velocity phase, and a deceleration phase. The rise times vary from 2 to 8 msec and the durations from 10 to 45 msec. This is in contrast to conventional, diaphragm-type air guns with approximately 0.3-msec rise time and less than 1-msec duration.

The range (acceleration amplitude and duration) of the simulator was determined to be as follows:

Acceleration parameters	Range
Rise time	2 to 8 msec
Duration	Approx. 10 to 45 msec
Amplitude	To 16,000 g's (at 21 lb)*
Spin rate	To 86 rps

The DMM has two high-capacity data channels (8K data points with 8-bit resolution) and 8 bi-level channels. It has performed well, providing an in-bore measurement capability not previously available. The DMM's durability and ruggedness in a high-g environment have been demonstrated as it continues to function after more than 50 test firings.

The simulator's order of magnitude increase in duration over diaphragm-type air guns, plus its spin capability, provides good simulations of gunfire shock parameters not otherwise reproducible in a laboratory facility. The similarity between gunfiring and simulator acceleration time curves makes it an acceptable, low-cost alternative to live firings for certain applications.

* The attainable g varies inversely with weight. With a 10% reduction in weight, the attainable g increase is 10%. The maximum attainable g is less at the longer durations.

ACKNOWLEDGMENTS

The author gratefully acknowledges the technical expertise and invaluable contributions of Frank Thoma, Bill Nord, and Tom Goodrich of the Commodity Evaluation Division, AED, ARDEC, for their efforts in performing the detailed assembly, instrumentation, and test firings required to conduct this project. Lou Szabo of the same organization is especially acknowledged for designing and developing the ARRT-66 digital memory module used to characterize the simulator.

CONTENTS

FIGURES

INTRODUCTION

A prototype 155-mm gas gun ballistic simulator was designed and construction begun at Frankford Arsenal to demonstrate the feasibility of simulating gun fire shock in a laboratory environment. The Army's decision to close Frankford Arsenal resulted in the relocation of the partially completed simulator to the present ARDEC Dover site, where it has been used for R&D type tests since it was installed in 1980. However, limitations in commercially available instrumentation prevented gun characterization and precluded its use in production testing.[1] Because of the lack of a data base, MTT Project 122-84/85 was initiated to document the simulator's acceleration-time history characteristics and to determine its suitability for production testing.

The broad goal of the project was to provide a cost effective alternative to live explosive gun firings through simulation of high-g impulse shock in a laboratory environment. The two tasks were to develop a lightweight digital memory module (DMM) that would operate in a high-g ballistic shock environment and to establish and document the characteristics of the simulator.

This report describes the DMM and ballistic simulator, summarizes the testing conducted, and documents the characteristics of the simulator (figs. 1 and 2). Testing details are published in a separate report (ref 1), which contains procedural details and describes problems caused by the high-g gun tube environment. A data base of acceleration time plots obtained during this program is contained in reference 2.

DISCUSSION

The simulator is basically a 155-mm gun with the rifling intact, a breech modified to accept a metering sleeve, and a 145 foot, closed-end extension to keep deceleration at an acceptable level (figs. 3, 4, and 5). A 13-inch metering sleeve controls the acceleration rise time by controlling the rate at which high pressure air in an annular volume flows into the gun, where it acts on the piston. As the piston approaches the end of the metering sleeve, the pressure behind the piston (and, hence, the acceleration) decay exponentially.

The acceleration rise time and duration can be changed by varying the configuration of the metering sleeve holes. The metering sleeve contains 90 holes that can be partially or fully closed by the insertion of threaded metal plugs. The amount and location of the openings determine the rise time and duration of

---

[1] Hardwired accelerometer data provided rise time and peak acceleration information. Characterization of the trailing portion of the acceleration pulse and all of the deceleration phase were prevented by the shearing of the accelerometer lead.

the acceleration by controlling the rate at which the air from the breech flows into the volume behind the piston. The peak acceleration level for a given hole configuration varies with the muzzle pressure. The level also depends on the payload weight (piston plus test item); the heavier the payload, the lower the peak acceleration.

The simulator can be used in either a linear or spin mode (fig. 6). In the spin mode, a piston containing slots is used, and rotation is imparted when the slots engage the rifling in the gun. When a linear piston is used, the rifling is not engaged.

The theory of operation is described in reference 3.

Digital Memory Module

To establish the dynamic characteristics of the simulator, in-bore acceleration and spin had to be measured. Consequently, the development of an instrument capable of measuring these parameters while surviving the high-g shock and spin gun environment was initiated. The use of an RF telemeter was considered. However, this approach, although feasible, would make the device too complex, costly, and bulky. Instead, a solid-state digital concept was pursued and a digital memory module (DMM), designated at the ARRT-66 telemeter, was developed (figs. 7 through 12). A block diagram is shown on figure 13, and a drawing of the DMM test fixture assembly, in figure 14.

The DMM is a micropower digital electronic device which acquires and stores data in solid state memory until interrogation. It uses basic digital design, implemented by state-of-the-art electronic components. It is a self contained, rugged, relatively low cost, highly shock resistant cylindrical package capable of measuring and recording high frequency data. It requires no significant modifications to the piston (such as provisions for an antenna for an r-f telemete The standby current drain is minimal; the rechargeable batteries are capable of retaining the data for several weeks if desired. Interrogation is simple. The digital data can be either converted to analog and viewed on a screen or transferred to a computer for analysis under software control

The durability of the DMM was also proven. Two units (the prototype and final design) were subjected to over 50 gun firings without apparent deterioration.

DMM Design Features

Electrical

1. Capacity:

   Analog: CH 1 and 2, 8K x 8 bits per channel

   Bilevel: CH 3 through 8, normally low, 8K x 1 bit per channel
   CH 9 and 10, normally high, 8K x 1 bit per channel

2. Front end configuration (CH 1 and 2): Programmable single ended or differential inputs

3. Signal conditioning: Instrumentation amplifiers are provided for CH 1 and CH 2 with independently programmable gains of up to 46 db.

4. Conversion rate: Programmable up to 1 MHz

5. Resolution (quantizing): 8 bits (CH 1 and CH 2)

6. Frequency response: 200 Hz per kHz conversion rate

7. Current drain, (standby): <5 microamps
   (write): <80 ma (200 msec typ.)

8. Readout: Nondestructive

9. DMM arming: Built-in time delay programmable from 1 minute to 1 hour

10. Supply voltage: 6 to 9 V dc (normal)
    <3 V dc (for data retention)

Environmental

1. Shock: 20 kg

2. Temperature, (operating): +20°F to +120°F
   (storage): -40°F to -150°F

Mechanical[2]

1. Size: 2.5 inches diameter x 8 inches length

2. Weight: 3 lb

General

Reuseability: Greater than 50 gun firings (proven)
Greater than 100 gun firings (estimated)

TESTING

Throughout 1985 and early 1986, a one channel, hard wired, prototype DMM was used to obtain simulator axial acceleration (setback) data.[3] In March 1986, satisfactory operation of a multichannel DMM using flexible printed circuit board was achieved during test firings. Since then, more than 50 test firings have been made to build up a data base. Both axial and tangential acceleration were monitored. Several metering sleeve hole configurations, including the extremes (shortest and longest rise times) were checked at various pressures to determine the range of the simulator (duration and amplitude). Testing was conducted with both the linear and spin pistons. The weights of the individual components and total test loads used in this investigation are shown in figure 15, the test chronology, in figure 16.

A single channel, hand wired, prototype DMM (64K chip, 6 bits, 1/64 resolution-timing circuits set for 180-msec data record time) was used in the initial testing. Two plots were made of each data record using different time scales; one at 20 msec per division (in order to observe the entire 180-msec data record) and another at 2 msec per division (for better resolution of the primary acceleration pulse).

Representative acceleration time curves obtained with the prototype DMM are shown in figures 17 to 22. The shortest rise time capability of the simulator is shown in figures 17 and 18, and the longest, in figures 19 and 20. An intermediate rise time configuration is shown in figures 21 and 22.

---

[2] Size was determined by cavity in fixture; size and weight could be smaller.

[3] The accelerometers used with the DMM were piezoresistive-type Endevco Model 2264A-20K-R's. Occasionally throughout the testing, data from an independent hardwire accelerometer (Endevco Model 2225, piezoelectric type) was monitored to verify the peak acceleration values (fig. 12).

Subsequent testing conducted with a multichannel DMM permitted the acquisition of tangential as well as axial acceleration data. The multichannel DMM has 8 bits (1/256 resolution), providing much better resolution than the prototype. Its timing circuit was set for a total data record time of 200 msec, during which it can store 8,192 data points. The data were filtered in the multichannel DMM circuit and the interrogator to minimize electrical oscillations and transients. The filters also attenuated high frequencies in the acceleration data so that the basic pulse is easier to observe. High frequency components of hard wire accelerometer data obtained (frequency response greater that 10 kHz) were not noticeably greater than the prototype DMM data shown. Frequency response for the prototype and the multichannel DMM is shown in the following table.

Component	Prototype DMM plots (kHz)	Multichannel DMM (kHz)
Piezoresistive accelerometer	16	16
DMM	8	2 (with filter)
Interrogator	8	0.850 (with filter)
X-Y plotter on 2 msec per div scale	6	6
Total system response	6	0.850

Representative acceleration time curves obtained with the multichannel DMM (figs 23 through 34) show spin piston data which include tangential as well as axial acceleration data. The low end of the simulator's range is shown in figures 29 and 30 which contain a 900 g, 15-msec pulse generated for a munitions project.

Representative acceleration pulses integrated to obtain velocity and displacement values are shown in figures 35 through 38.

The acceleration time curves for the test firings were reduced to obtain the peak acceleration values. Curves were then plotted to show the relationship between peak acceleration and breech pressure for representative metering sleeve hole configurations (figs. 1 and 2). These curves categorize the amplitude range of the simulator. The total weight applicable to each curve is shown. Higher g is obtainable with lighter payloads; less g, with heavier payloads.

GENERAL CHARACTERISTICS

Accelerometer data from simulator firings at various metering sleeve hole configurations were reviewed and analyzed to determine the pulse shape, rise time, duration, amplitude, spin rate, and angular acceleration capabilities of the simulator. These characteristics are summarized as follows:

Initial Axial Acceleration Pulse

Pulse Shape

Accelerometer data show that the setback pulse is asymmetric with a sinusoidal-shaped leading edge and a trailing portion that decays exponentially.

Rise Time and Duration

The fastest acceleration rise time is approximately 2 msec and the longest approximately 8 msec. Total pulse durations varied from 10 msec to approximately 45 msec.

Amplitude

Acceleration levels from 900 to 14,000 g's were obtained during these tests. Higher levels are achievable with lighter payloads. (Acceleration levels of 15,000 g have been achieved during testing of munitions components.) The attainable g increases 10% with a 10% reduction in weight. If lower values than 900 g's are desired, they can be attained by adding weight to the carrier piston. (Weights of the carrier pistons used for these tests are shown on figure 15.) The maximum acceleration level attainable decreases at longer pulse rise times and durations (figs. 1 and 2).

Similarity to Gun Firing Shock

Both gun firing and simulator acceleration time curves plotted on the same scale are shown in figure 39. The similarity between the two curves suggests that, for certain applications, the simulator would provide an acceptable alternative to live firings.

After Initial Axial Acceleration Pulse

The basic acceleration pulse (10 to 45 msec duration) is followed by a nearly constant velocity phase (for approximately 100 to 150 msec) and then a deceleration phase. The magnitude of the deceleration phase varies; for most configurations and set pressures, it is approximately 10% of the setback acceleration.

Spin Rate

The angular velocity (spin rate) can be calculated from the axial velocity (rifling engaged) by the following relationship:

$$\omega = \frac{2\pi}{nd} \nu \text{ axial}$$

where

ω = angular velocity in radians per sec

Spin rate (Hz) $= \frac{\omega}{2\pi}$

n = Calibers (25 for 155-mm gas gun)

d = 6.1 inches (for 155-mm gas gun)

The maximum velocity attainable in the simulator is limited by the gas medium used. Velocities of approximately 1100 fps were obtained from integration of acceleration-time pulses. At 1100 fps or 13,200 inches per second, the following results:

$$\frac{2 \times 3.14 \times 13{,}200}{25 \times 6.1} = 544 \text{ radians per second}$$

$$\text{Spin rate} = \frac{\omega}{2\pi} = \frac{544}{6.28} = 86.6 \text{ revolutions per second}$$

For lower velocities, the spin rate will be less.

Angular Acceleration

The angular acceleration can be calculated from either the axial acceleration (rifling engaged) or the tangential acceleration. An example (for Firing No. 302) follows.

From Measured Axial Acceleration

$$\alpha = \frac{2\pi}{nd} A \text{ axial}$$

where

α = Angular acceleration in radians per sec^2

n = Calibers (25 for 155-mm gas gun)

d = 6.1 inches (for 155-mm gas gun)

A axial = Axial acceleration in inches per sec^2

= 10,225 g's (from axial acceleration time curve)

= 10,225 x 386.1 = 3,947,873 inches per sec^2

$$\alpha = \frac{2 \times 3.14 \times 3,947,873}{25 \times 6.1} = 163K \text{ radians per sec}^2$$

From Measured Tangential Acceleration

A tangential = r α

where

r = Effective radius of accelerometer in inches

= 1.05 inches (as mounted)

α = Angular acceleration in radians per sec^2

A tangential = Tangential acceleration in inches per sec^2

= 440 g's (from tangential acceleration time curve)

= 440 x 386.1 = 169,884 inches per sec^2

$$\alpha = \frac{A \text{ tangential}}{r} = \frac{169,884}{1.05} = 162K \text{ radians per sec}^2$$

ACTUAL TESTING APPLICATION

Early in this investigation an inquiry was received relative to a gun simulator application for a munitions project in which a small component would be subjected to a 900 g, 15-msec shock. The specified 900-g acceleration level is at the low end of the simulator's range and, at the time of inquiry, the simulator's performance could not be verified to meet this need.

After DMM development, however, tests were conducted and the simulator did meet the required acceleration time profile. Verification curves, in the form of acceleration time plots, were obtained for documentation purposes (figs. 29 and 30). The DMM total data record time of 200 msec was also long enough to capture the deceleration phase. The data were given to the responsible program engineer and it is anticipated that the simulator will be used in the next similar application.

CONCLUSIONS

The 155-mm gas gun ballistic simulator provides a cost effective laboratory testing tool not previously available. A key advantage of the simulator is that components are recovered almost immediately and are undamaged by impact, as in field firings. It is also economical to use, readily available, and testing is not cancelled or delayed because of weather as in the field. The acceleration amplitudes and durations generated by the simulator can be varied within its operational range to provide good simulations of some gun fire shock parameters which are not otherwise reproducible in a laboratory facility. The order-of-magnitude increase in duration over diaphragm-type air guns, plus its spin capability, makes the simulator useful for a variety of applications in which conventional diaphragm-type air guns would be unsatisfactory.

In-bore measurement capabilities have been advanced with the successful development of a compact, rugged, reusable, multichannel, state-of-the-art DMM. The high-g DMM technology is evolving with development underway at several locations. The technological advance essential to this successful effort was the recent availability of improved microcircuits. It is anticipated that this device will have broad application in the measurement of in-bore gun tube environments. Techniques and procedures have been perfected to the degree that similar devices are expected to be manufactured economically (non-developmental) at ARDEC.

REFERENCES

1. Karlsen, Anders, "155-mm Gas Gun Ballistic Simulator--Development Test Documentation," Explosive Test Unit Test Report, AMCCOM Project No. 122-84/85, ARDEC, Dover, NJ, in press.

2. Karlsen, Anders, "155-mm Gas Gun Ballistic Simulator--Data Base of Acceleration Time Histories," Explosive Test Unit Test Report, AMCCOM Project No. 122-84/85, ARDEC, Dover, NJ, in press.

3. Wiland, James, "Development of the 155-mm Ballistic Simulator," Technical Report FA-TR-74023, Frankford Arsenal, Philadelphia, PA, August 1974.

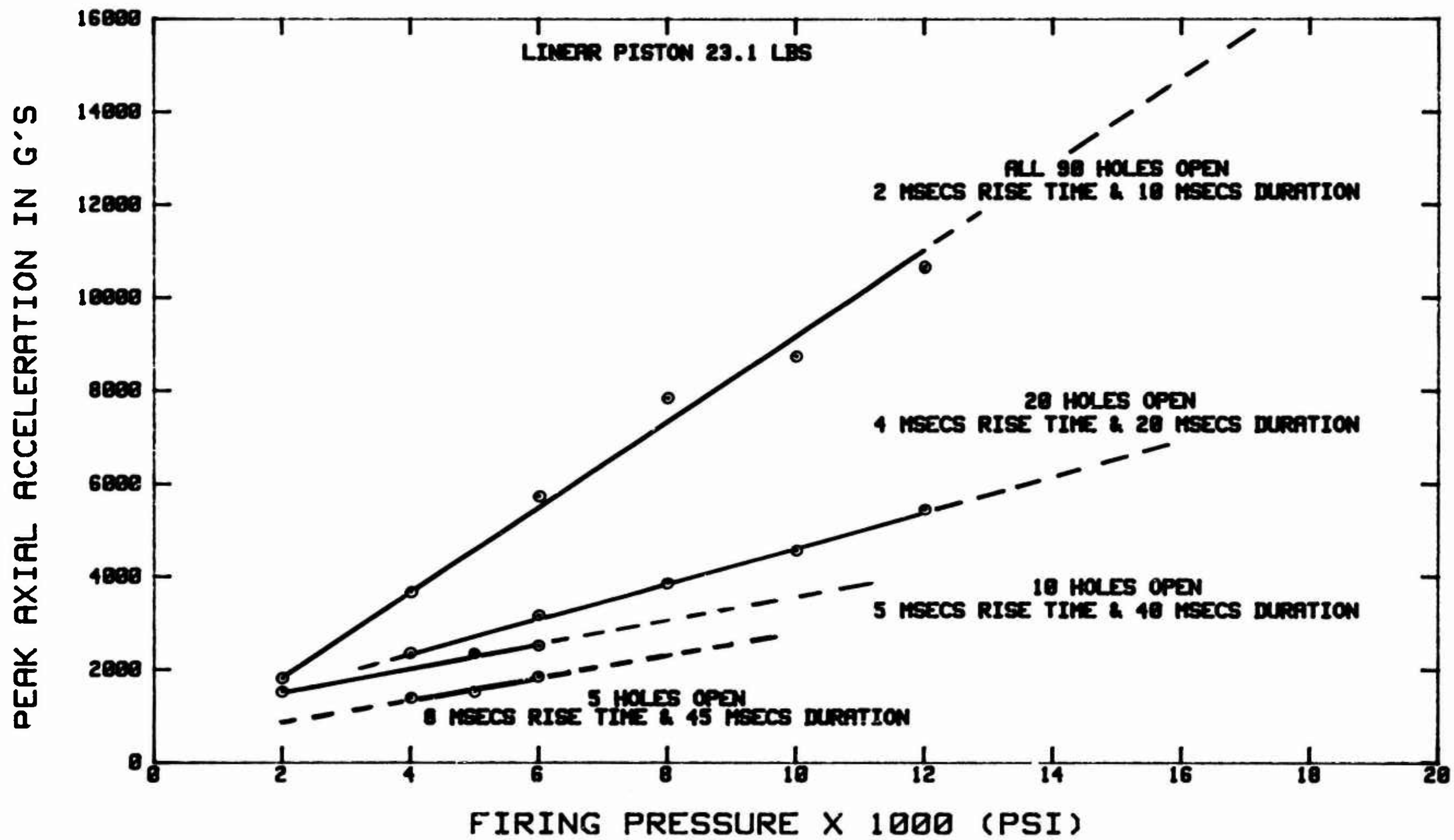

Figure 1. Prototype DMM test data

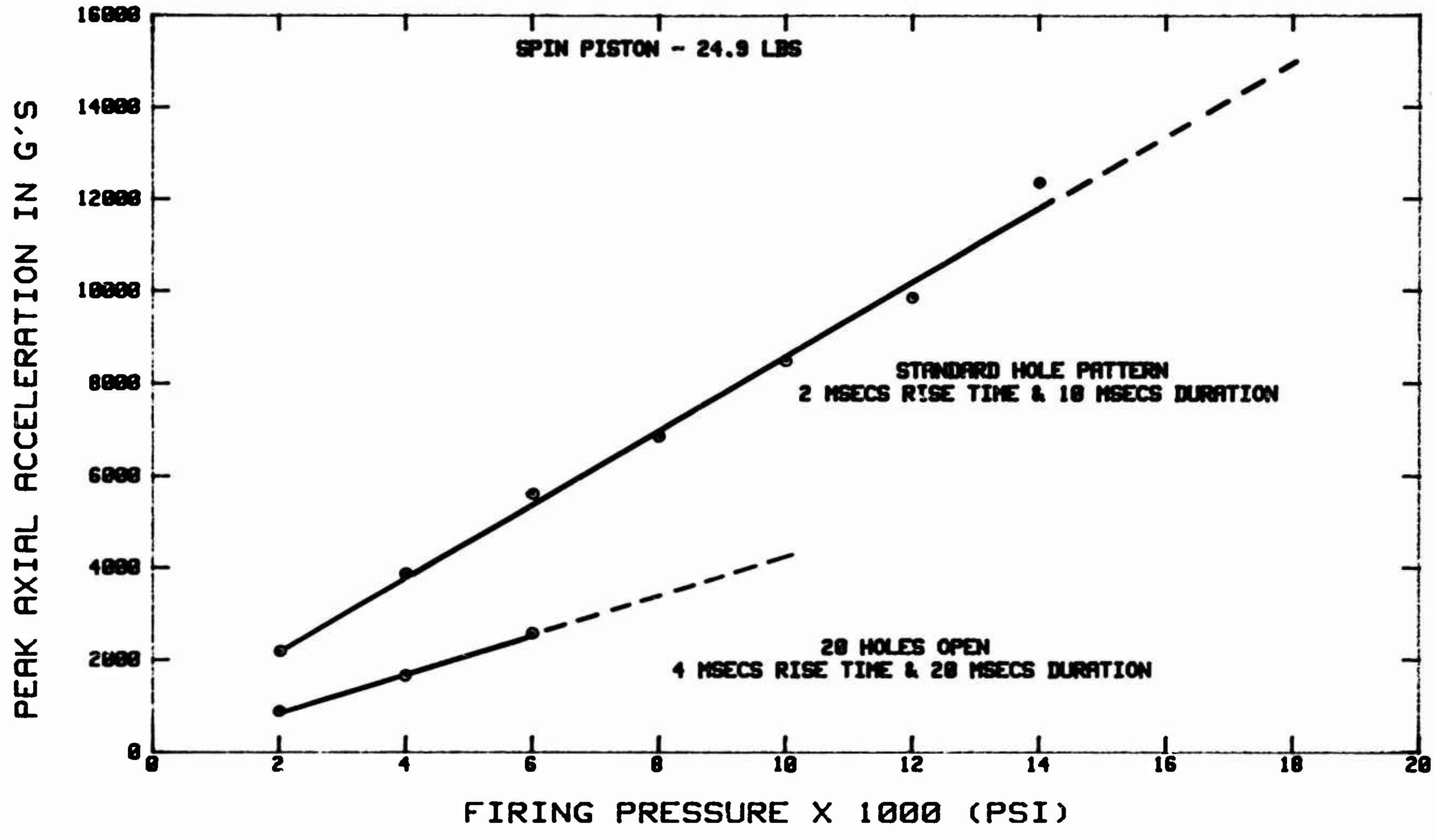

Figure 2. Multichannel DMM test data

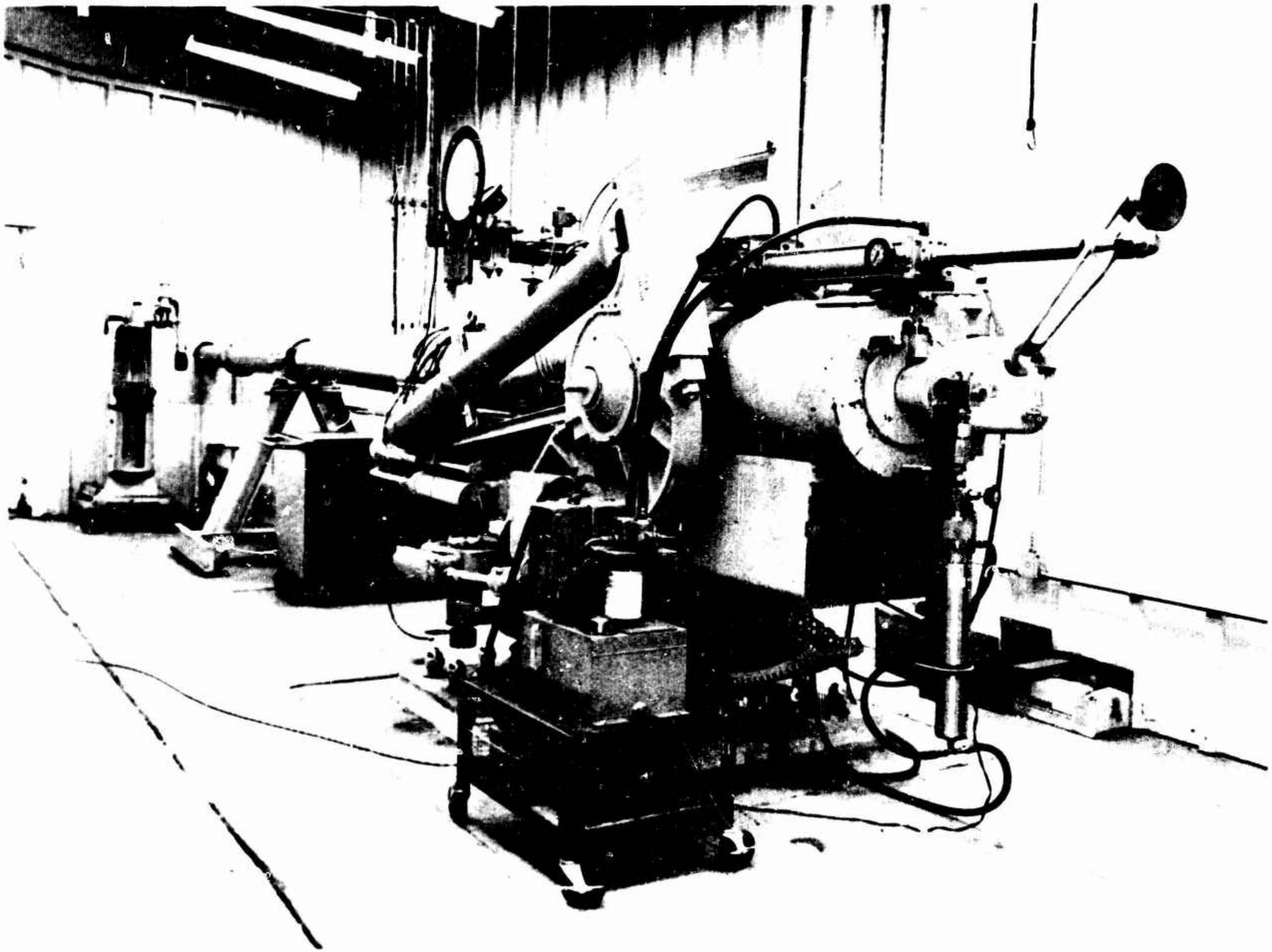

Figure 3. Ballistic simulator, breech end

Figure 4. Ballistic simulator, muzzle end

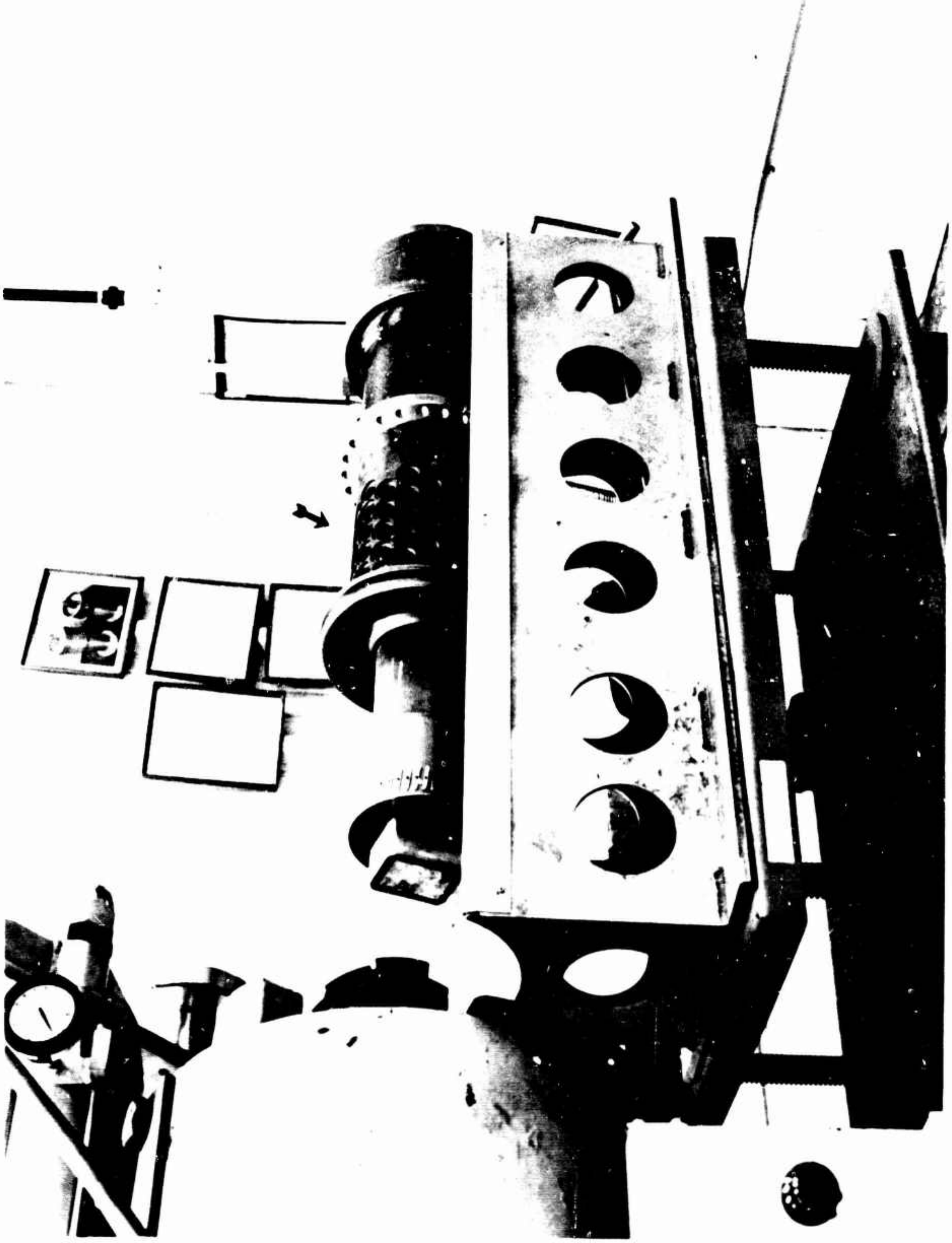

Figure 5. Breech components

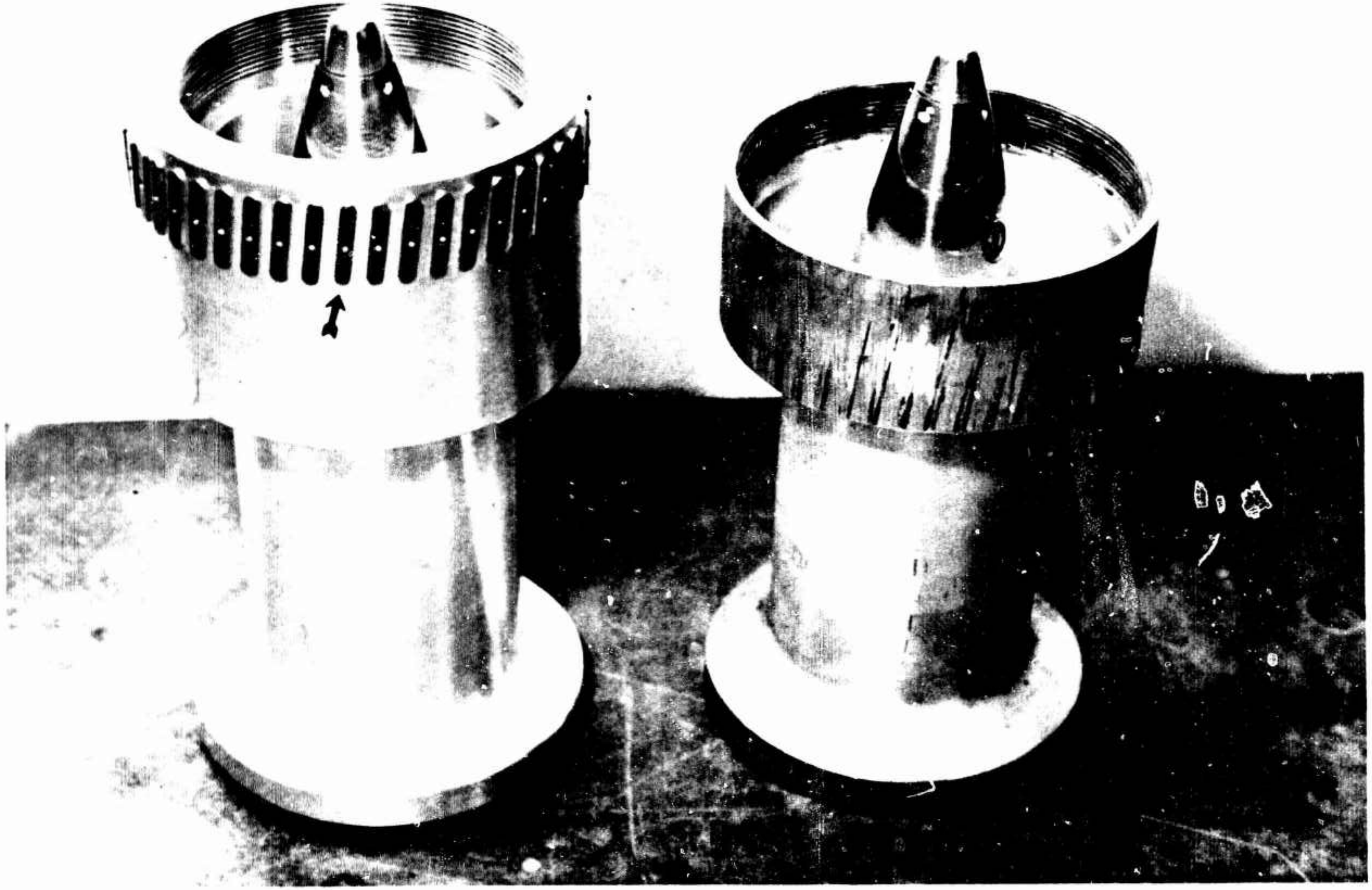

Figure 6. Spin piston and linear piston

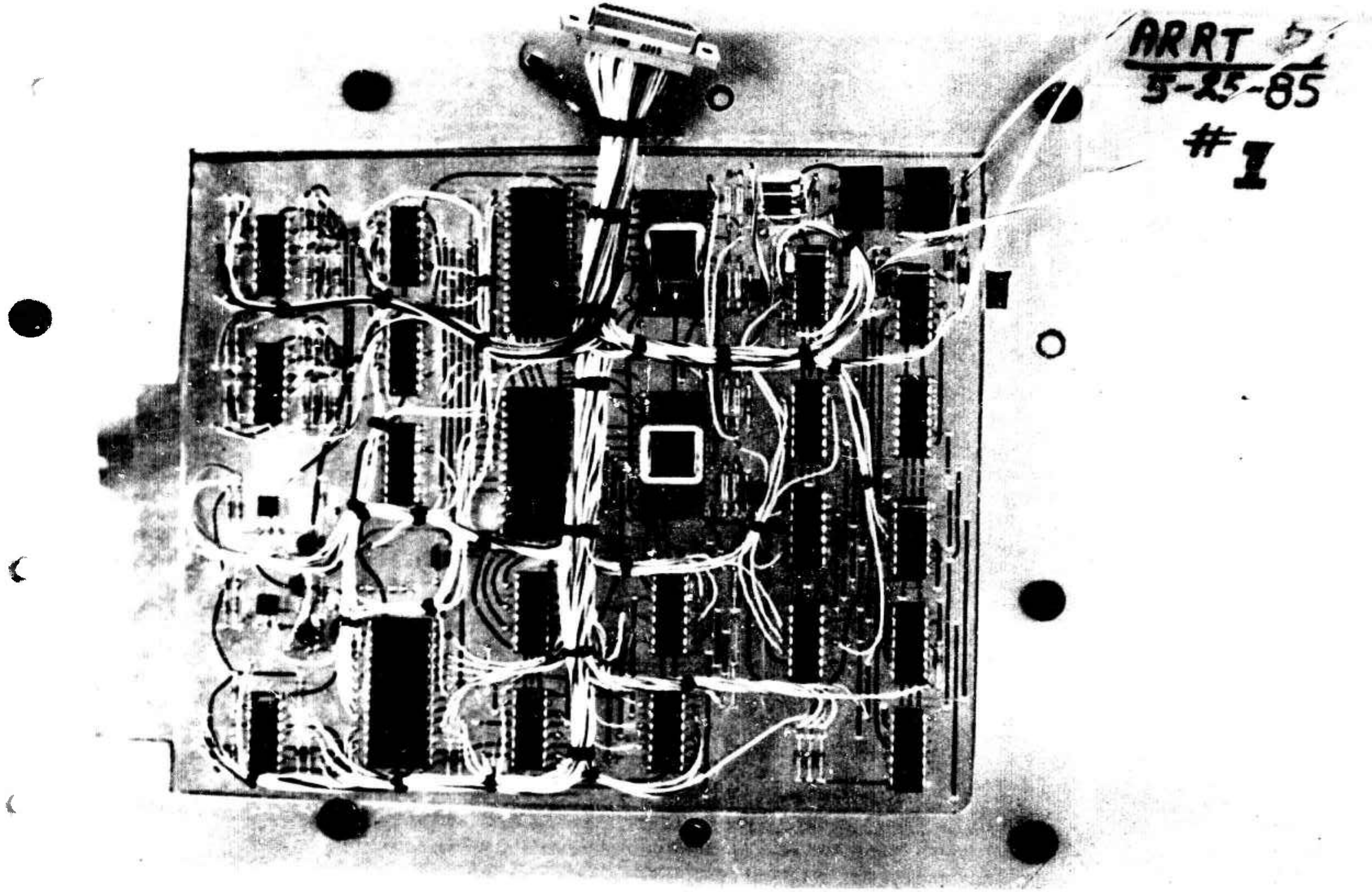

Figure 7. ARRT-66 DMM printed circuit board

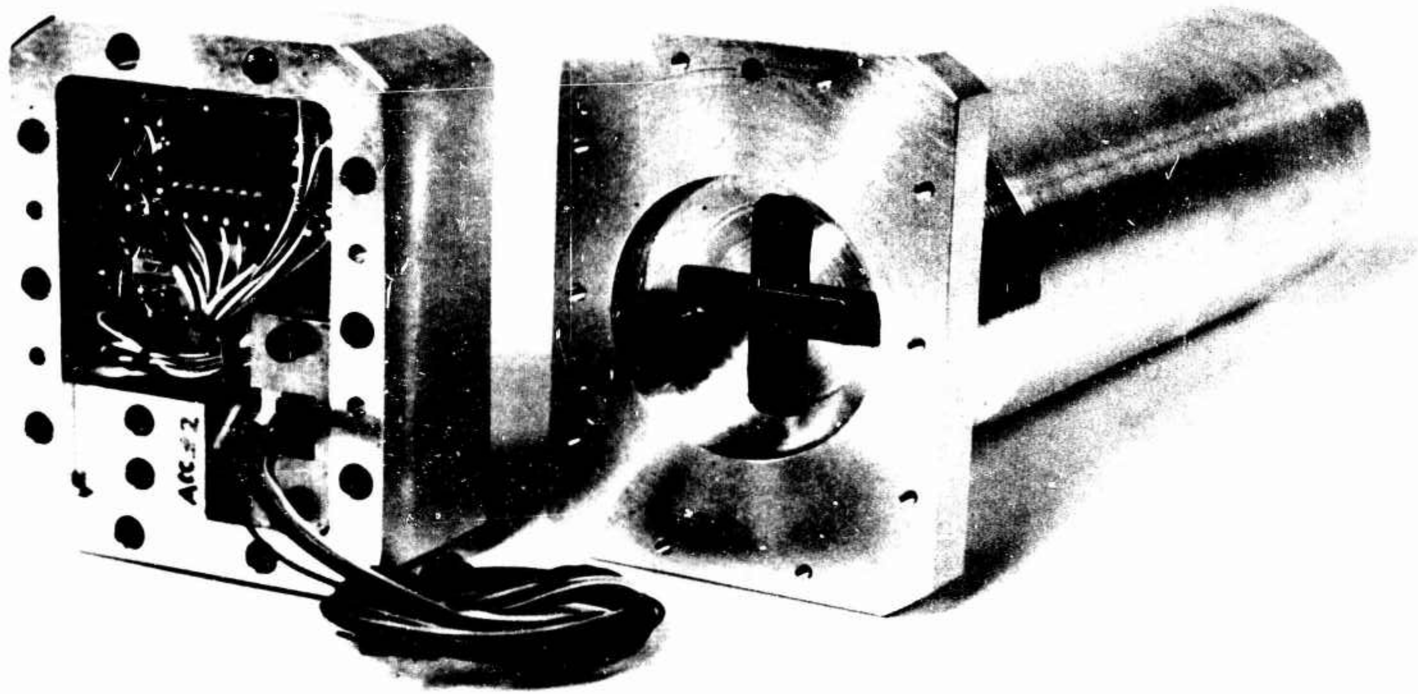

Figure 8. Acceleration module (cover removed) and DMM

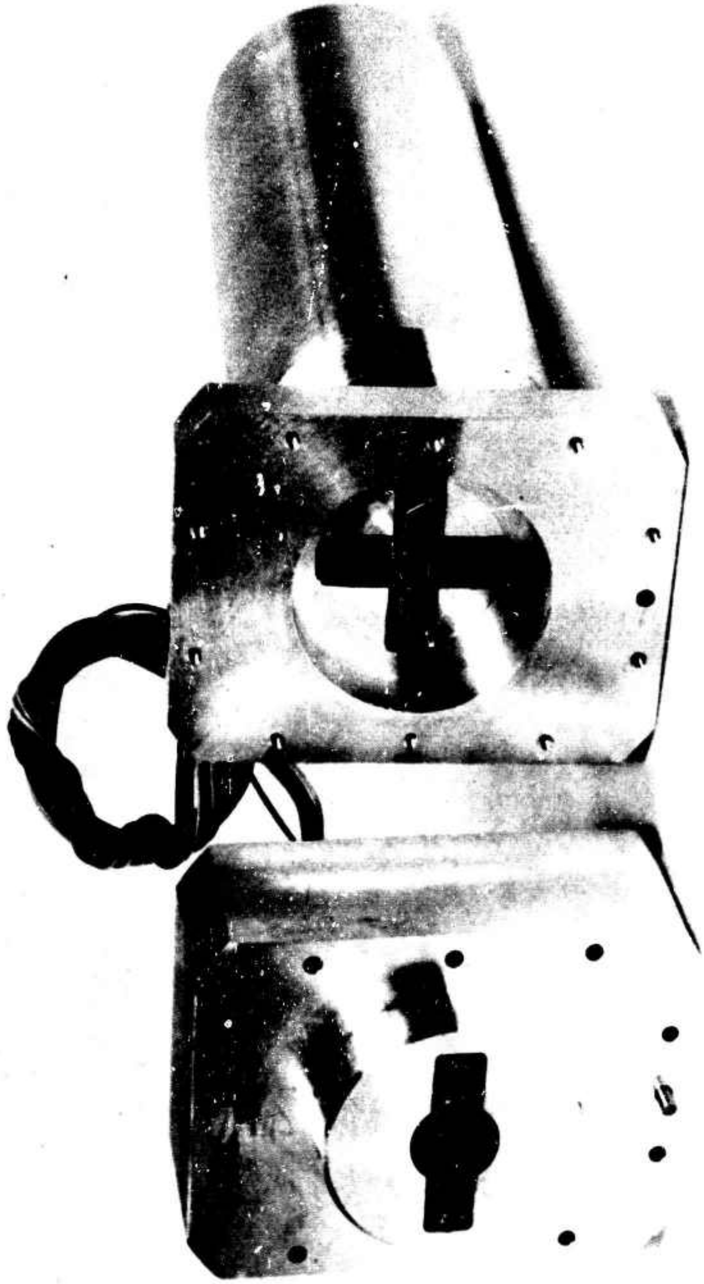

Figure 9. Acceleration module (connector end) and DMM

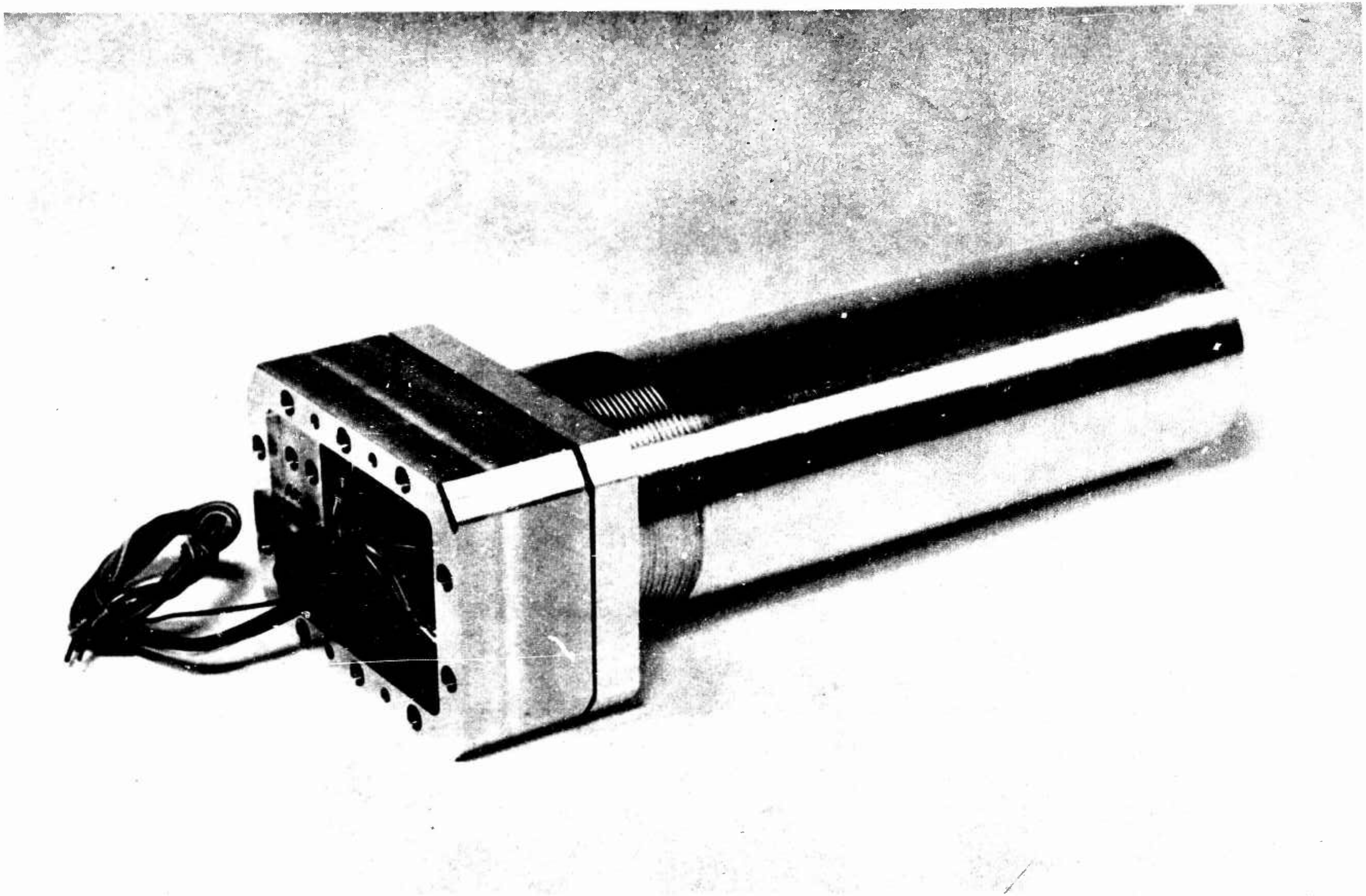

Figure 10. ARRT-66 DMM Assembled

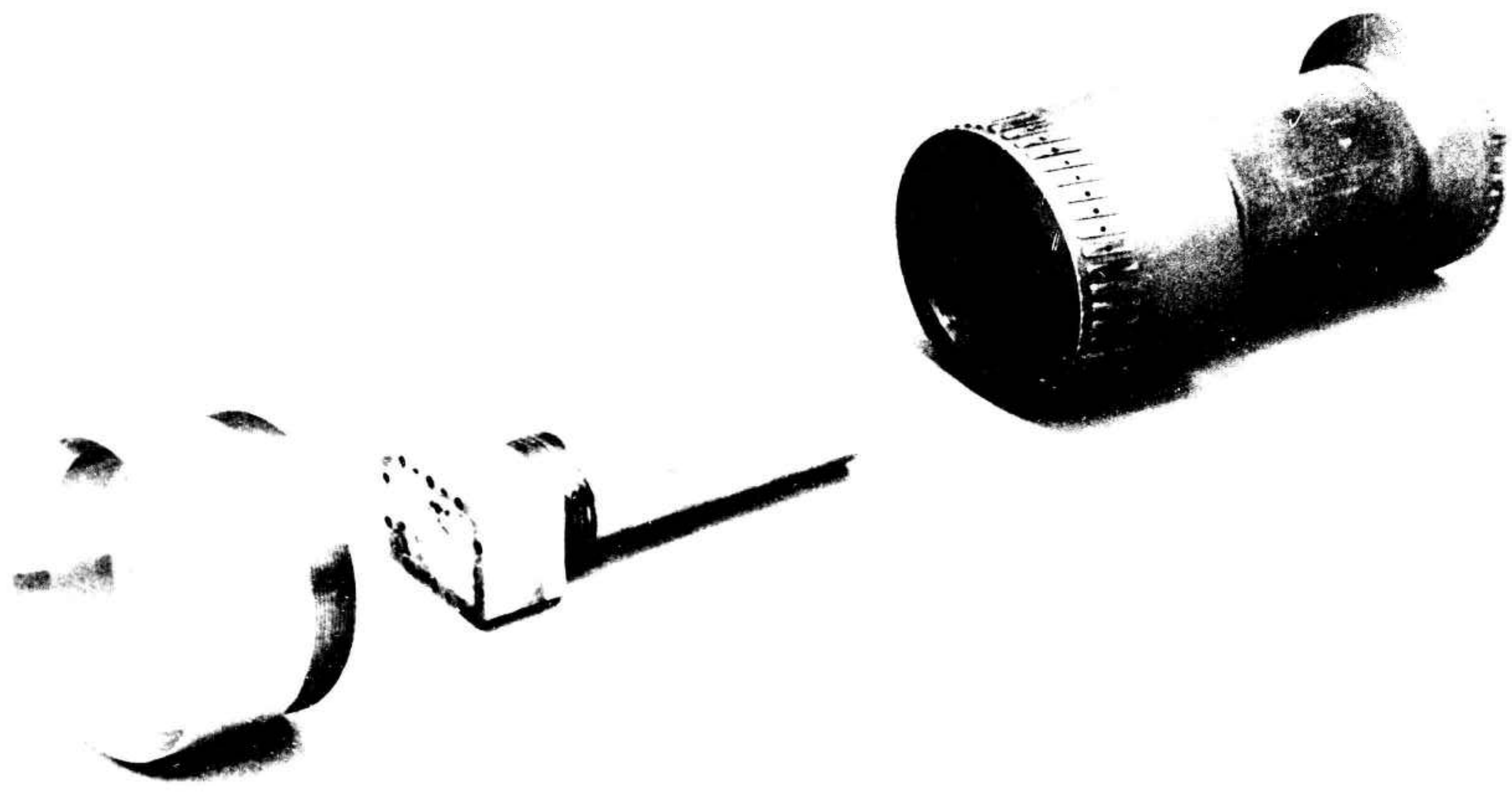

Figure 11. Scoop, DMM, and spin piston

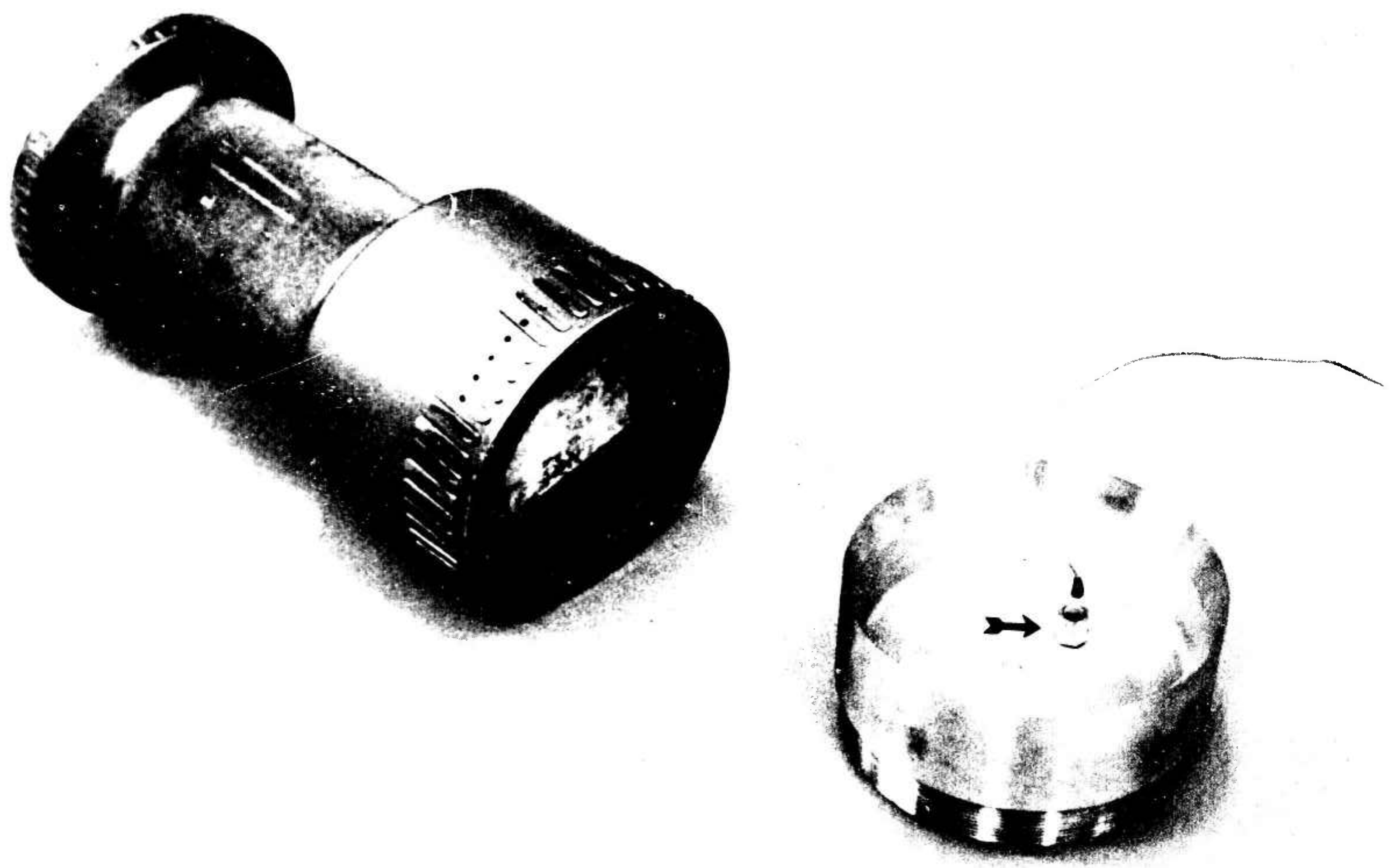

Figure 12. Spin piston and scoop

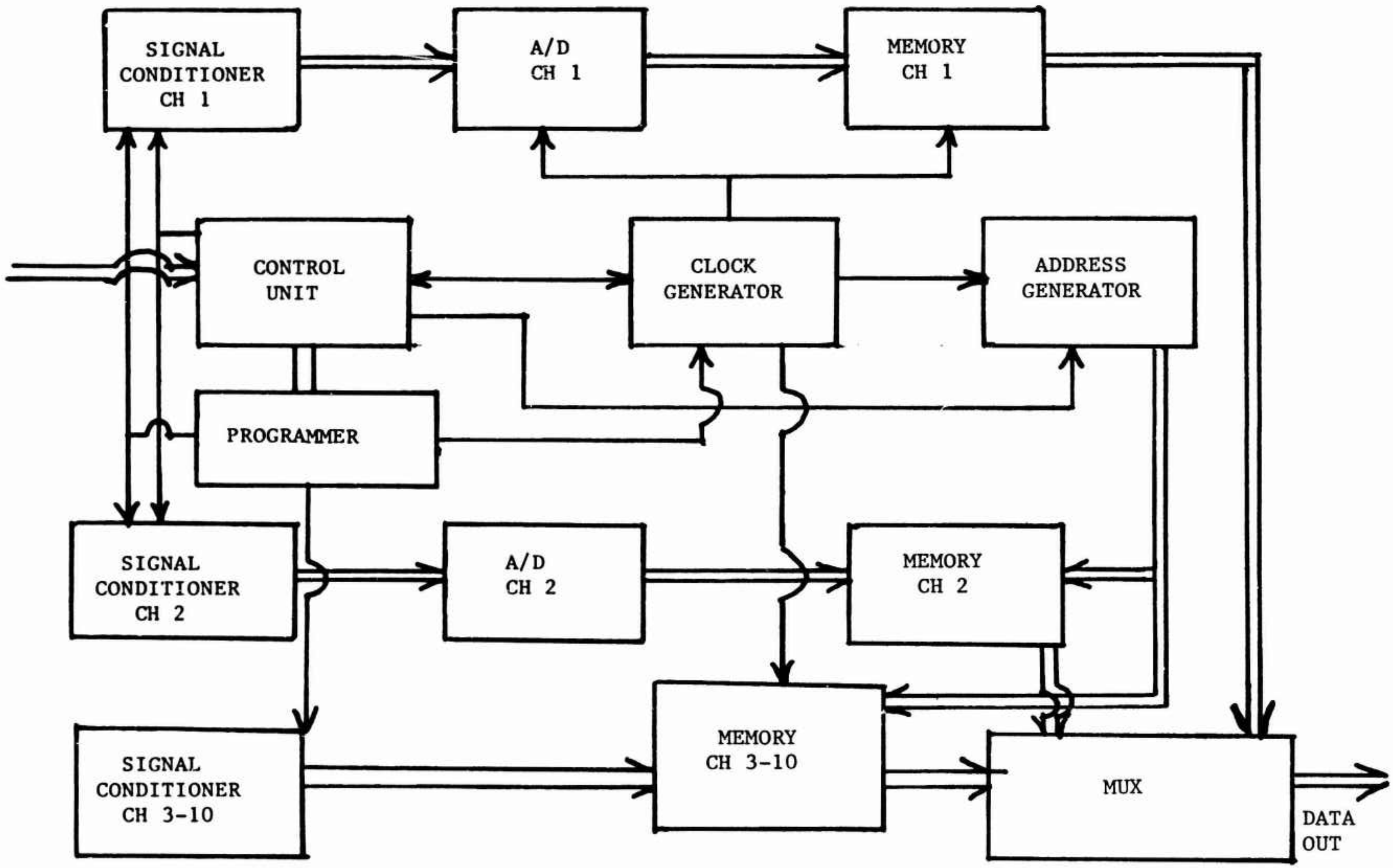

Figure 13. ARRT-66 DMM functional diagram

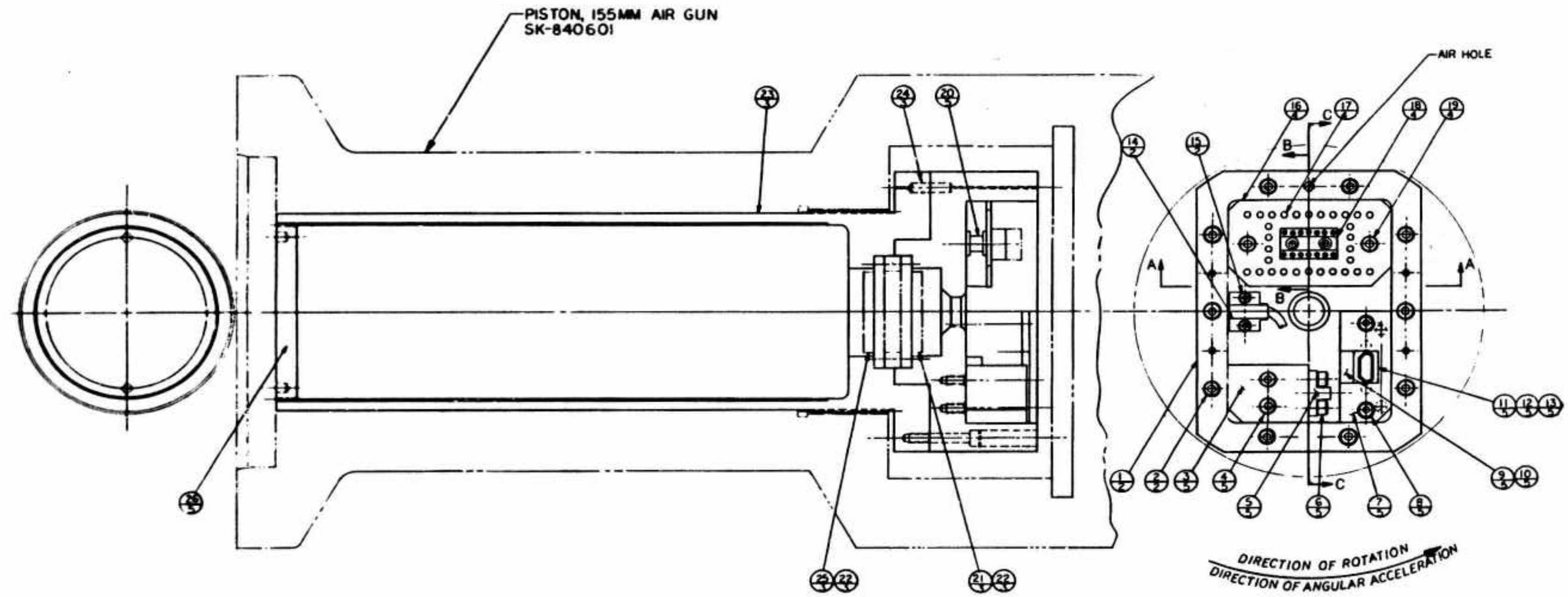

Figure 14. ARRT-66 TM, test fixture assembly

INSTRUMENTED BALLISTIC SIMULATOR TESTS

Component	Weight (lb)
Multichannel DMM (including accelerometer module with screws	4.265
Assembled Linear Piston with multichannel DMM	24.3
Assembled Spin Piston with multichannel DMM	24.9
Prototype (single channel) DMM (including accelerometer module with screws)	3.05
Assembled Linear Piston with prototype DMM	23.1
Assembled Spin Piston with prototype DMM	23.8

BREAKOUT OF ASSEMBLED SPIN PISTON WITH MULTICHANNEL DMM

Multichannel DMM		3.03
Accelerometer module with screws		1.235
Spin Piston		16.395
Scoop		4.07
Wooden spacer		0.165
	Total	24.895

Figure 15. Test weights

CHRONOLOGY

PROTOTYPE DMM (SINGLE CHANNEL-HANDWIRED - 6 BITS - S/Ns 1 & 2, 16K CHIP - S/N 3, 64K CHIP)-AXIAL ACCELERATION MONITORED

DATE	TEST FIRING #	PROTOTYPE DMM S/N	INFORMATION
9/26/84	125	1	First Proof Test - No data obtained - Module damaged in test.
11/1/84	132	2	Proof Test - Successfully obtained axial acceleration data.
1/18-24/85	147 to 157	2	Initial Data - One of 6 bits defective limiting resolution and data quality.
4/30 - 5/3-85	170 to 181	3	Initial Data - Investigate shortest and a long rise time configuration.
5/30 - 6/13-85	186 to 213	3	Initial Data - Investigate various hole configuration patterns.
8/19 - 9/19-85	224 to 258	3	Initial Data - Investigate several hole configurations with Spin Piston.

NOTE: PROTOTYPE DMM S/N 3 STILL FUNCTIONAL AFTER 57 TEST FIRINGS.

DMM (10 CHANNEL - FLEXIBLE PRINTED CIRCUIT BOARD - 8 BITS - 64K CHIP) AXIAL AND TANGENTIAL ACCELERATION MONITORED

DATE	TEST FIRING #	DMM #	INFORMATION
11/15/85	267	1	First Proof Test - No data obtained. Suspected cause, wiring deficiencies.
11/19/85	268	1	Proof Test - No data obtained. Suspected cause defective components.
11/26/85	271	1	Proof Test - No data obtained. Cause undetermined.
2/14/86	287	2	Proof Test - No data obtained. Cannon "equivalent" connector cracked. Circuit board stretched due to void in potting.
3/26/86	299	3	Proof Test - Successfully obtained axial and transverse acceleration data.
4/16/86	302 & 303	3	Check Test - Independent hardwire verification of axial acceleration. Comparison of Spin and Linear Pistons.
4/22 - 6/12-86	320 to 367	3	Characterization of Simulator.

NOTE: DMM S/N 3 STILL FUNCTIONAL AFTER 52 TEST FIRINGS.

Figure 16. Test chronology

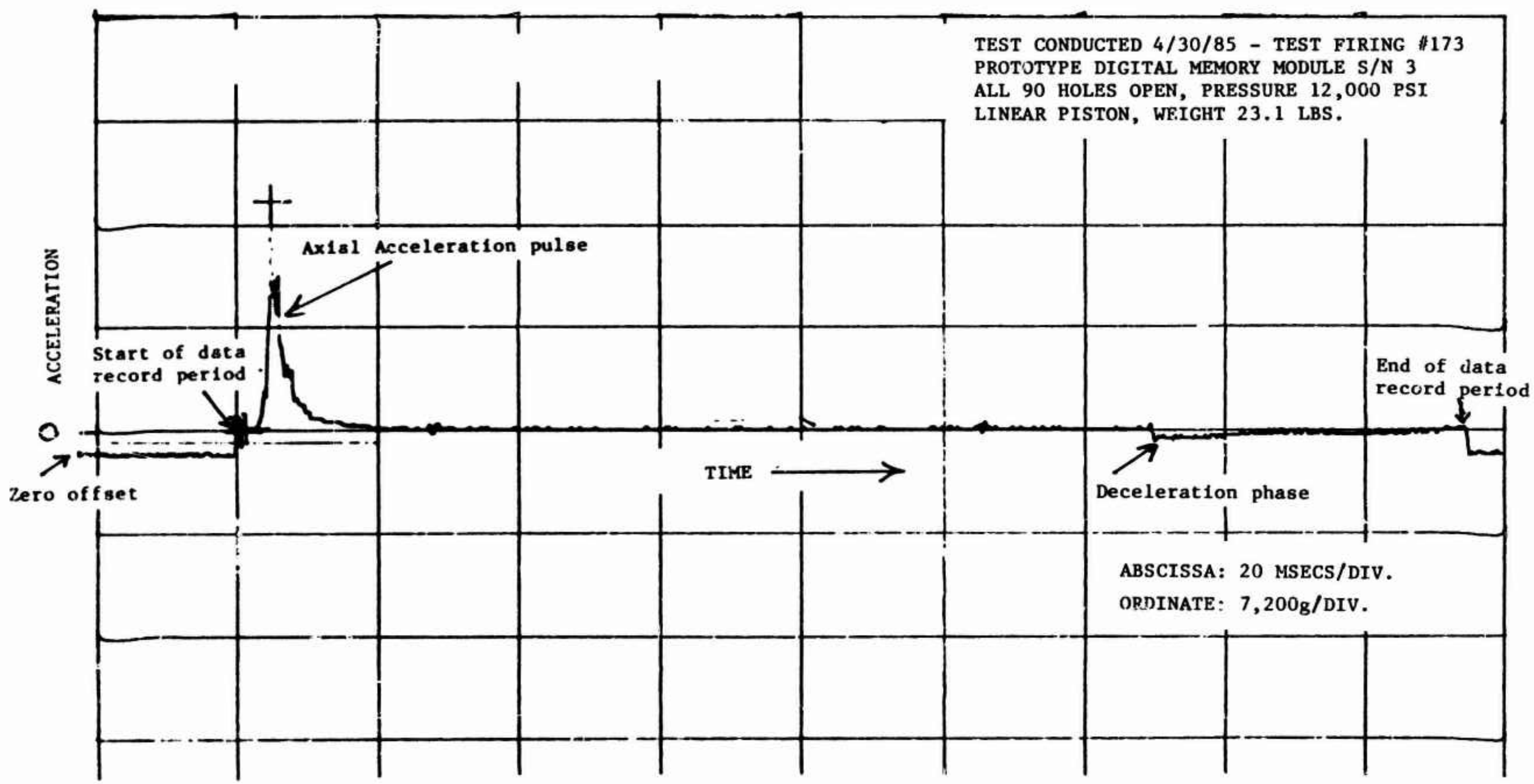

Figure 17. Axial acceleration, prototype DMM, shortest rise time, 20 msec per div.

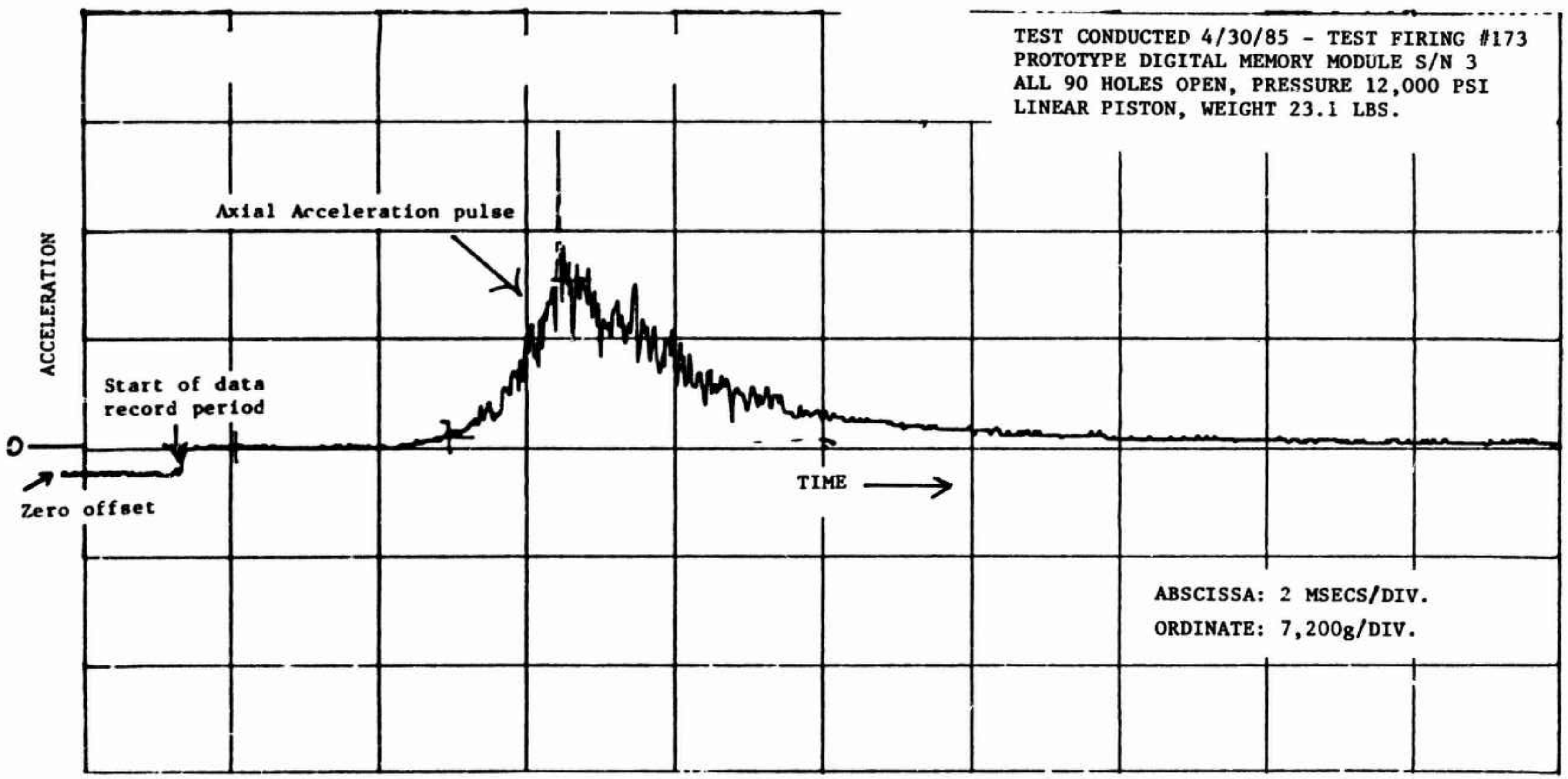

Figure 18. Axial acceleration, prototype DMM, shortest rise time, 2 msec per div.

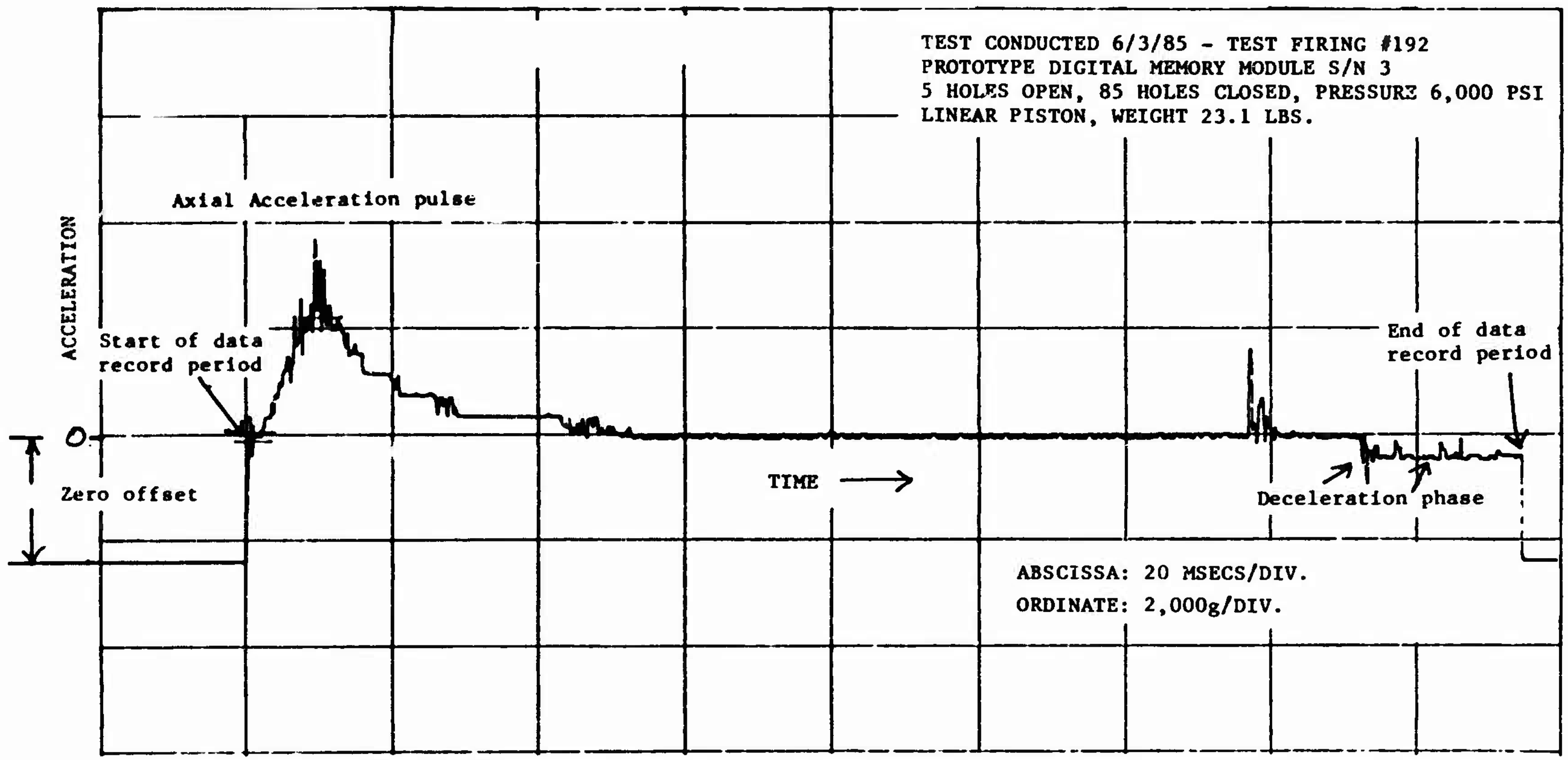

Figure 19. Axial acceleration, prototype DMM, longest rise time, 20 msec per div.

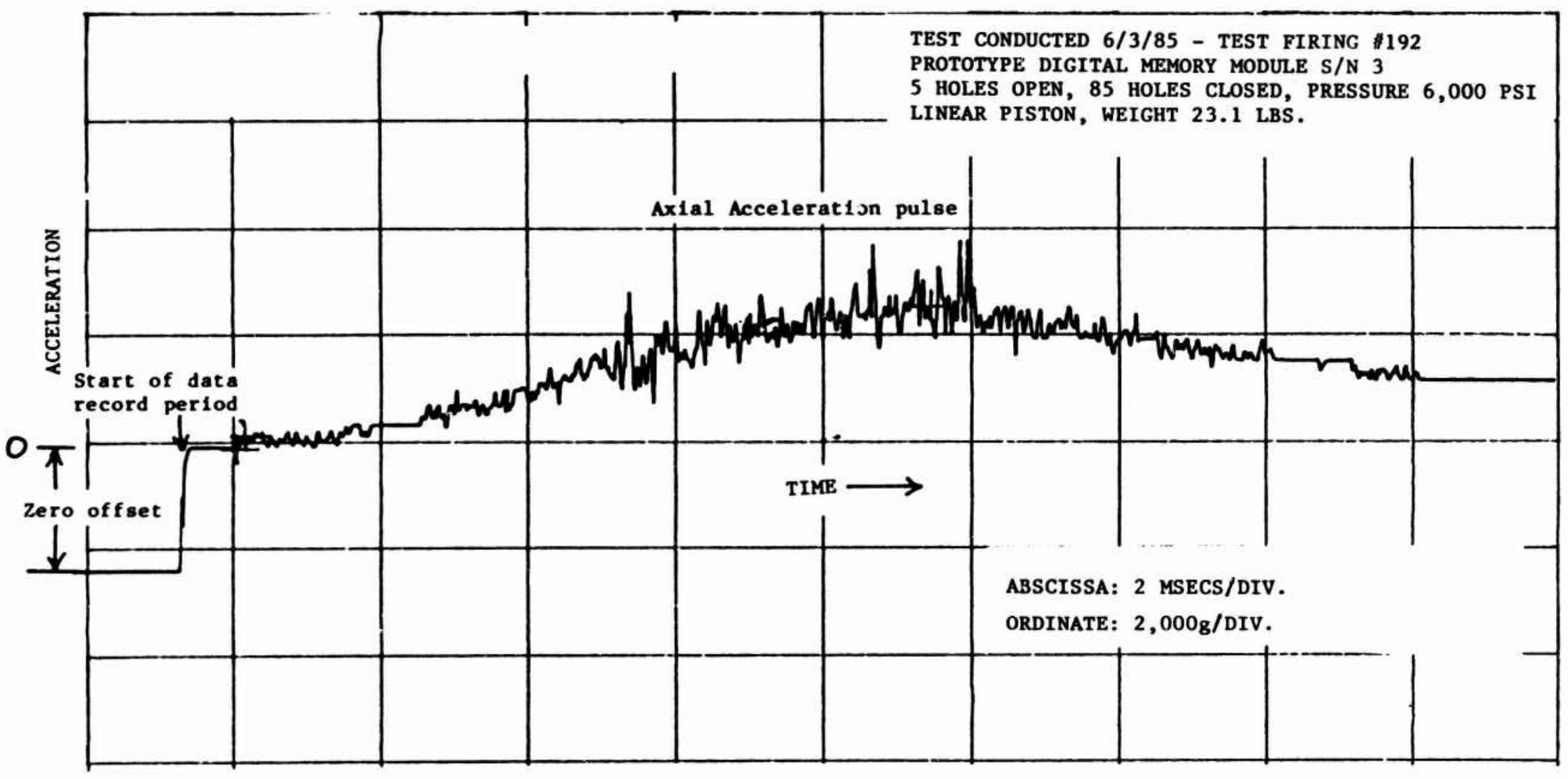

Figure 20. Axial acceleration, prototype DMM, longest rise time, 2 msec per div.

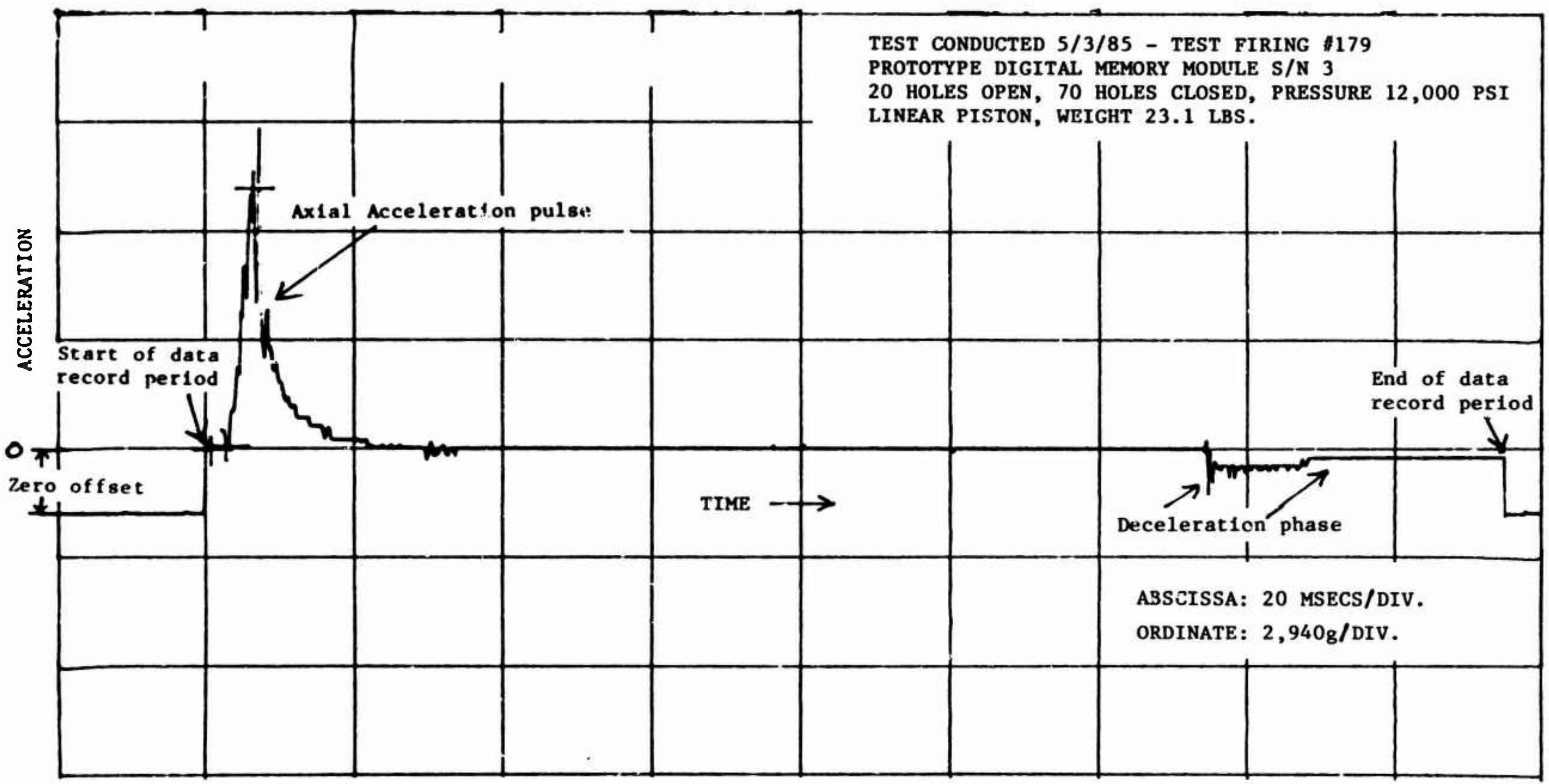

Figure 21. Axial acceleration, prototype DMM, intermediate rise time, 20 msec per div.

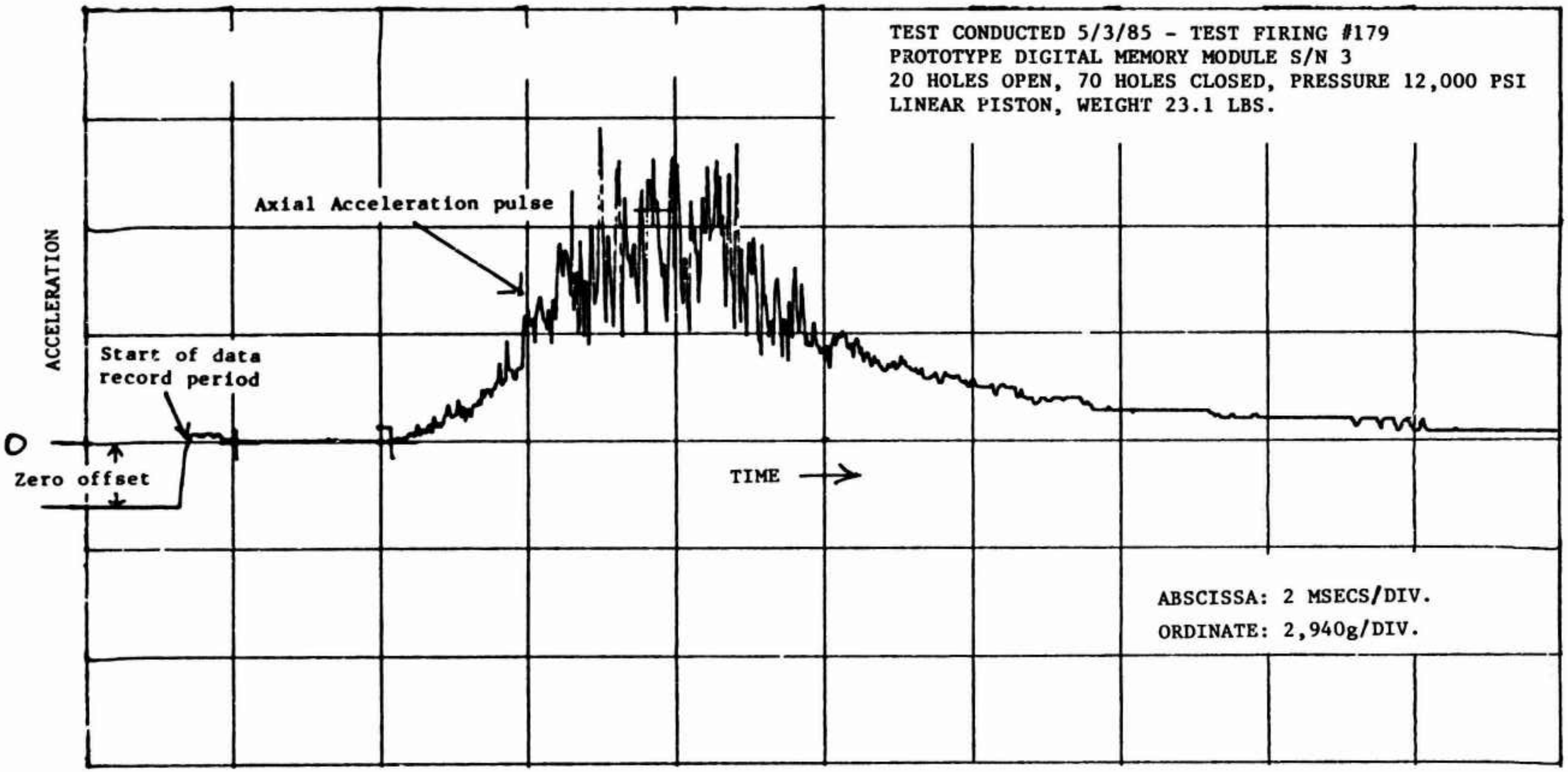

Figure 22. Axial acceleration, prototype DMM, intermediate rise time, 2 msec per div.

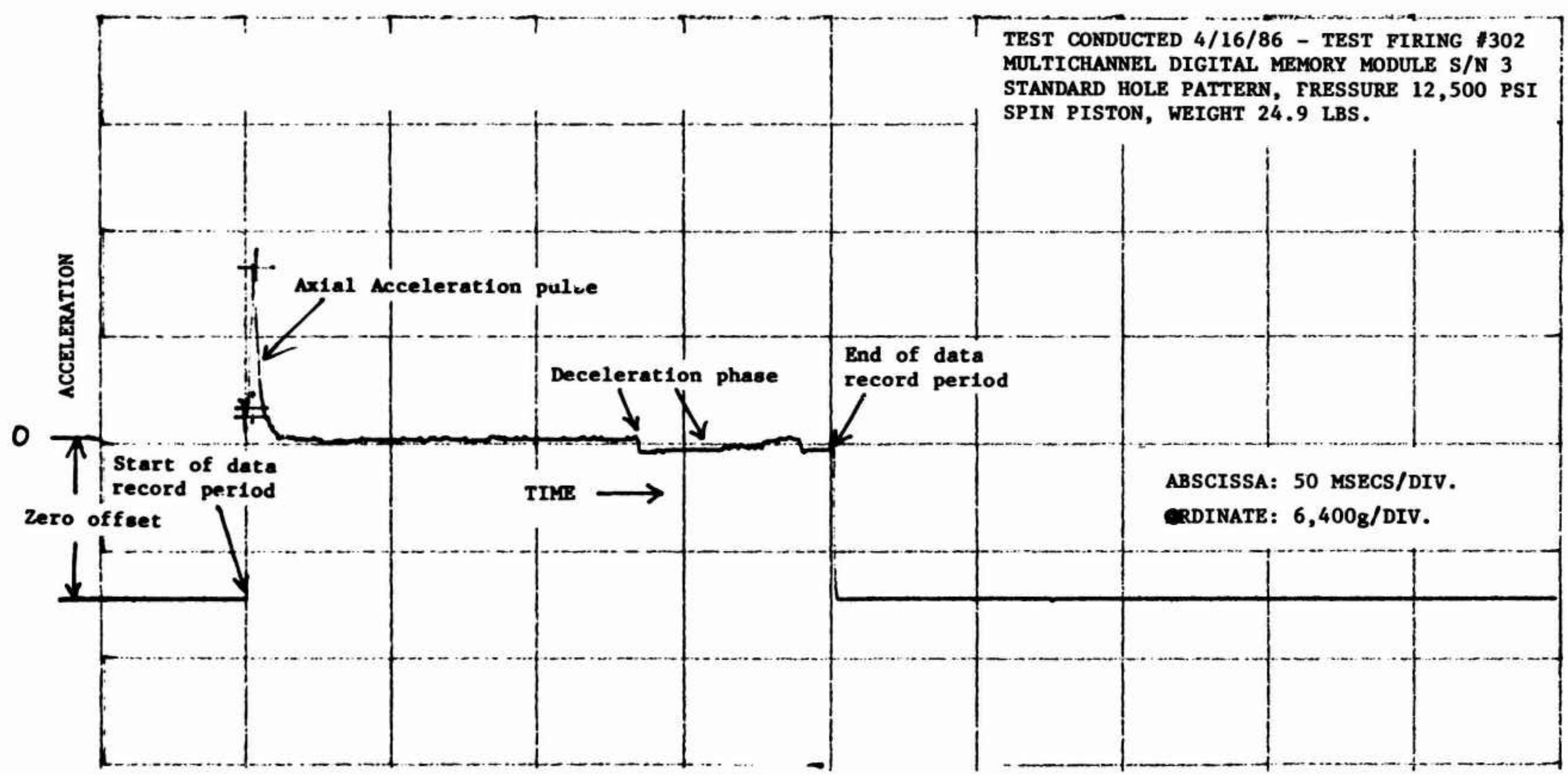

Figure 23. Axial acceleration, multichannel DMM, spin piston, firing 302, 50 msec per div.

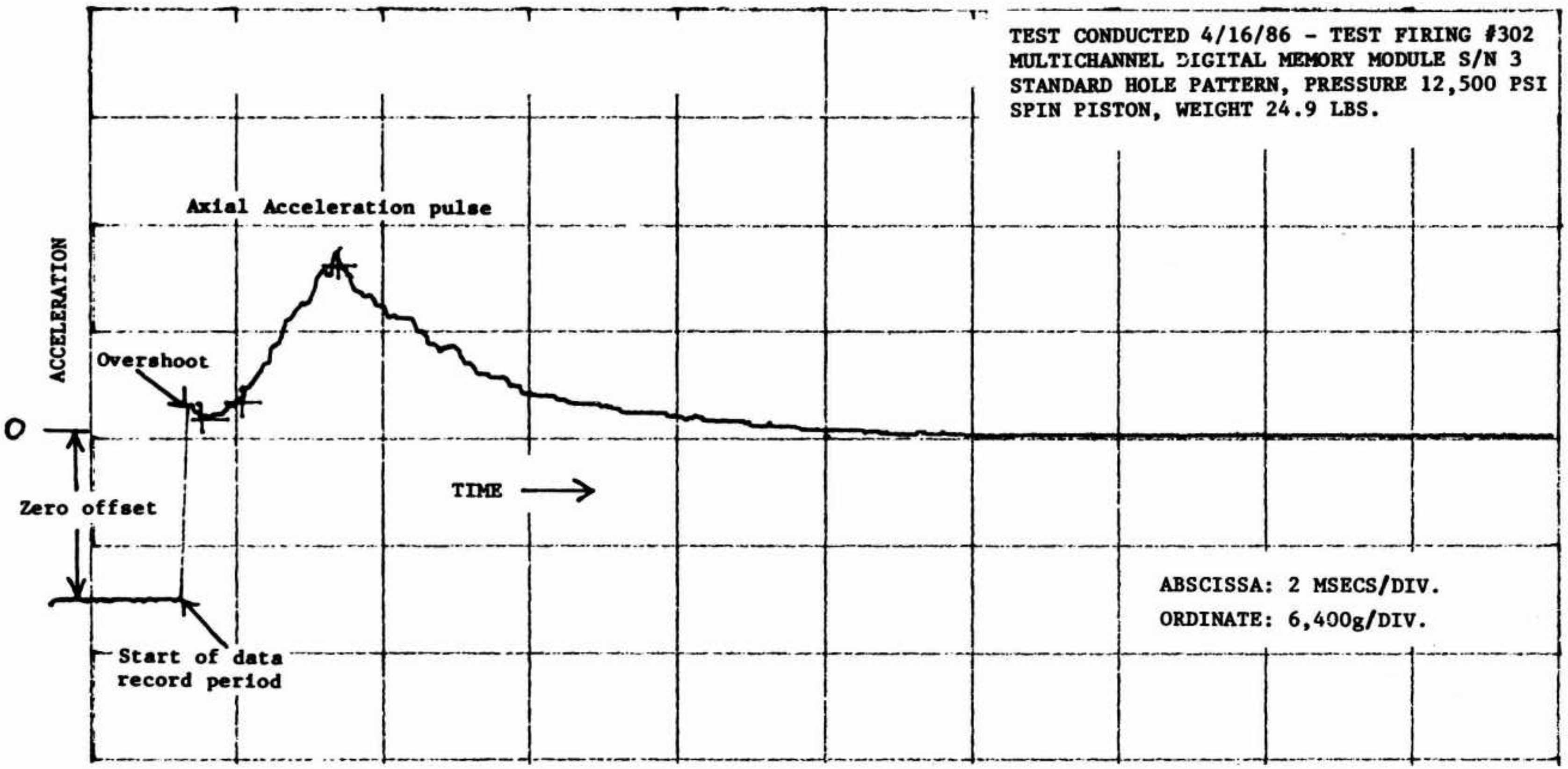

Figure 24. Axial acceleration, multichannel DMM, spin piston, firing 302, 2 msec per div.

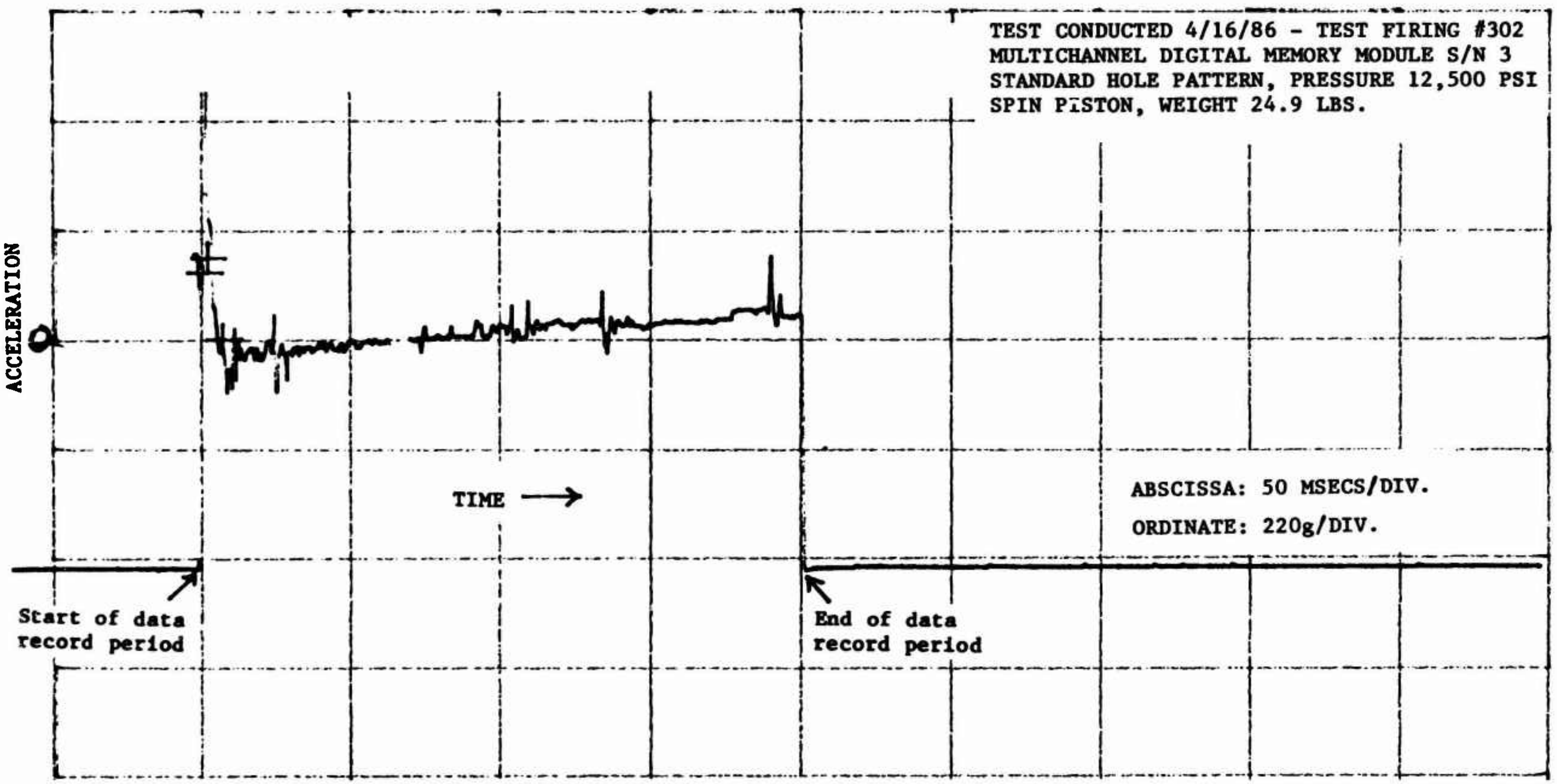

Figure 25. Tangential acceleration, multichannel DMM, spin piston, firing 302, 50 msec per div.

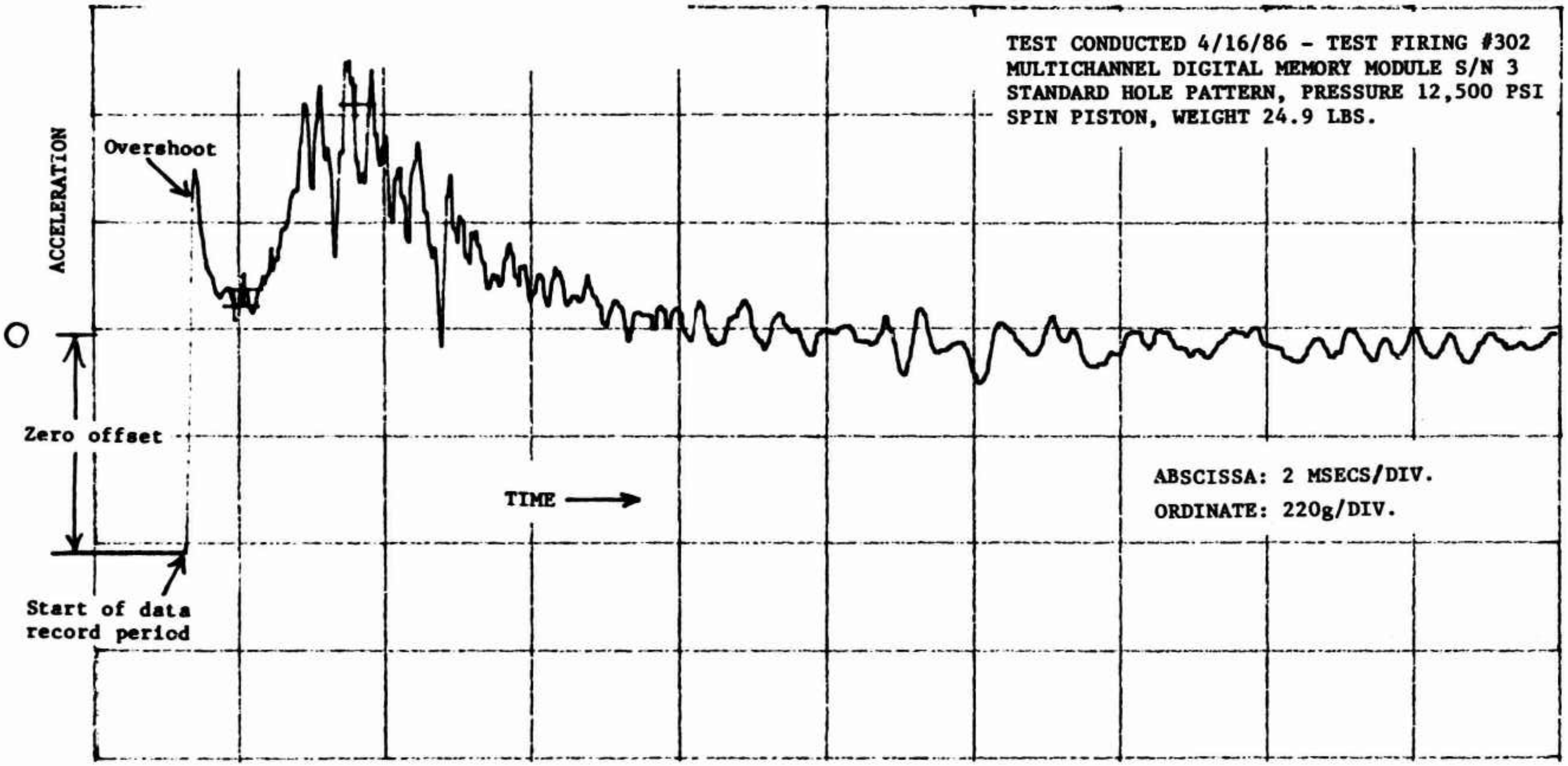

Figure 26. Tangential acceleration, multichannel DMM, spin piston, firing 302, 2 msec per div.

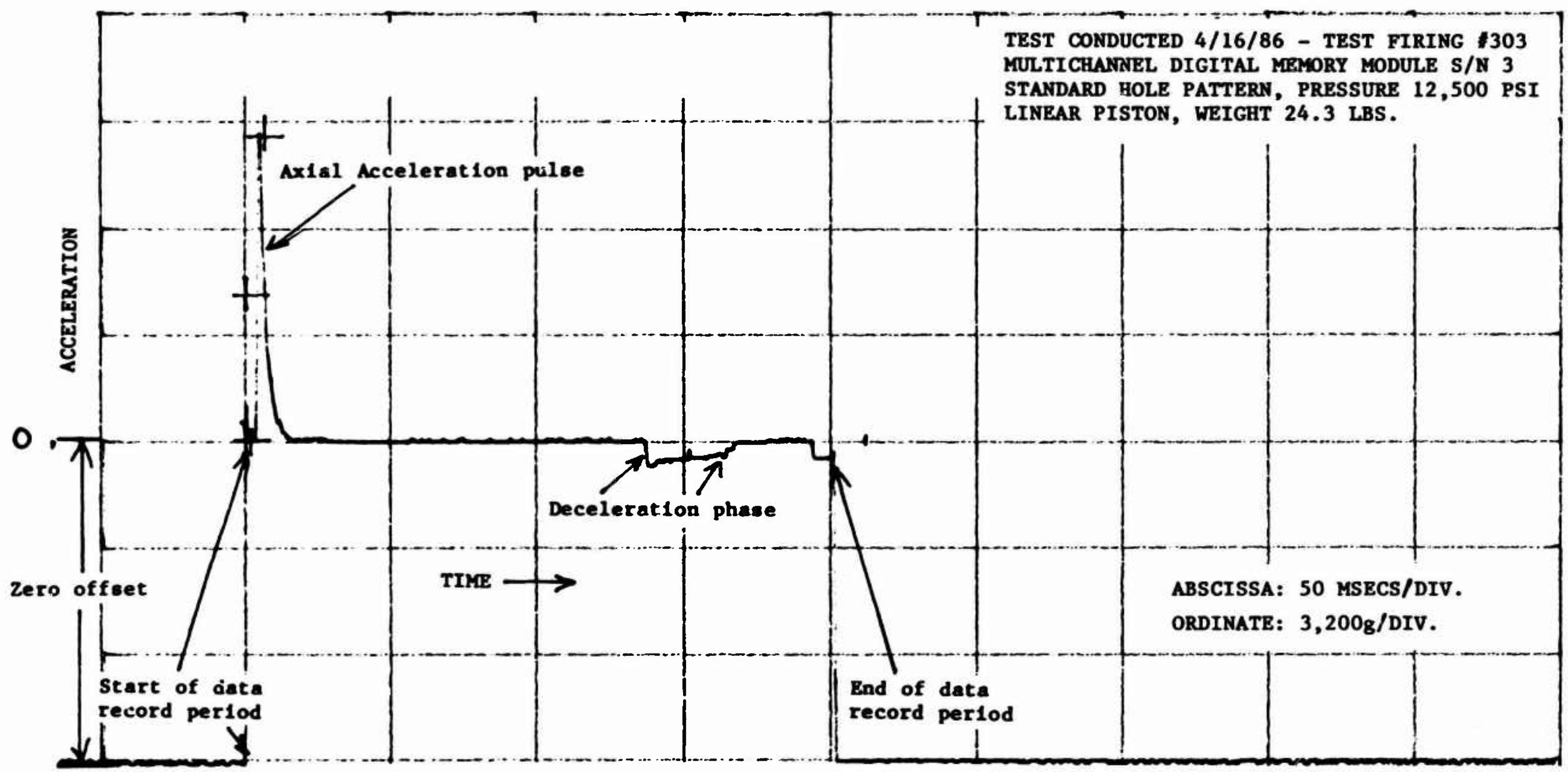

Figure 27. Axial acceleration, multichannel DMM, linear piston, firing 303, 50 msec per div.

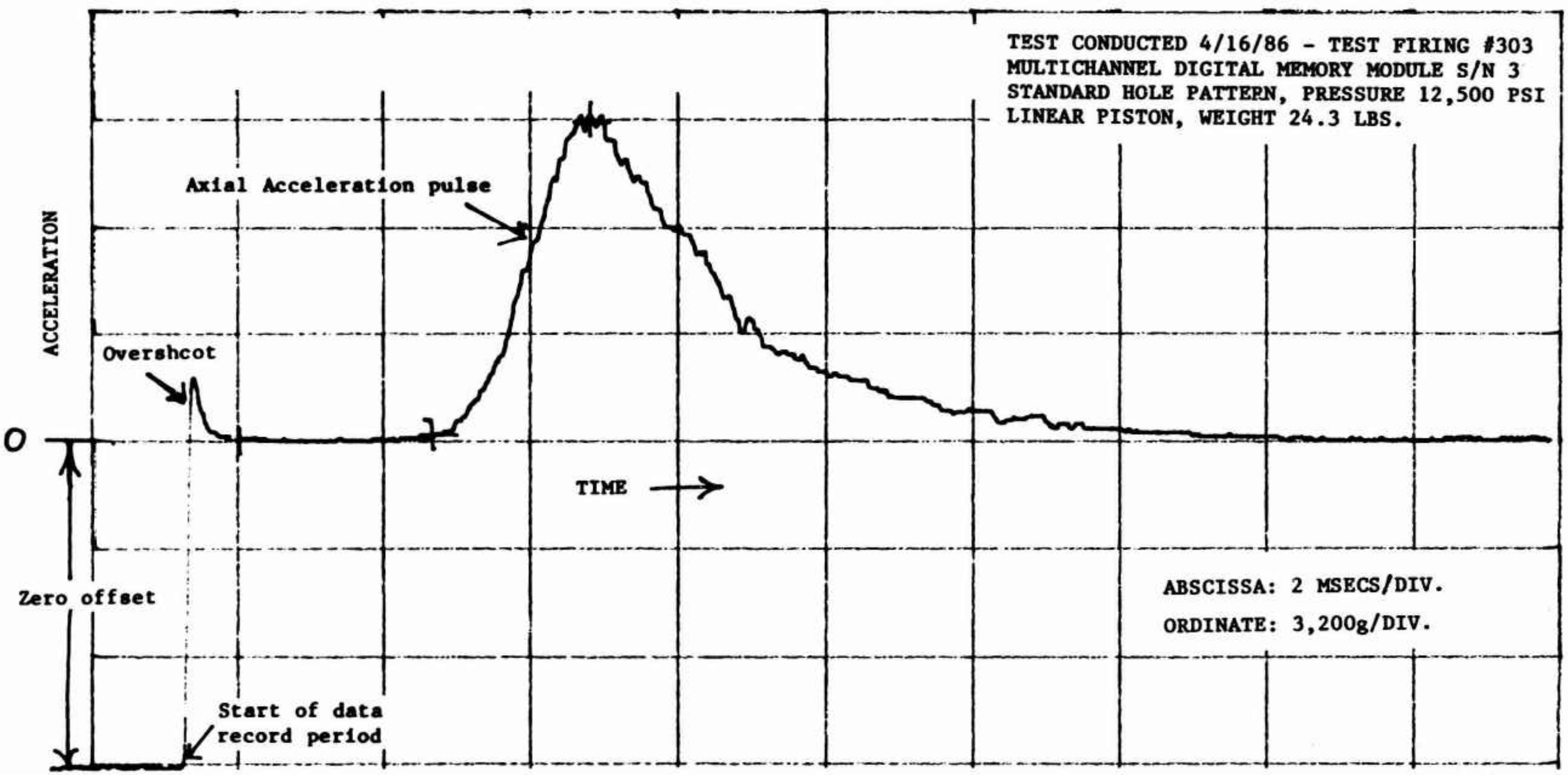

Figure 28. Axial acceleration, multichannel DMM, linear piston, firing 303, 2 msec per div.

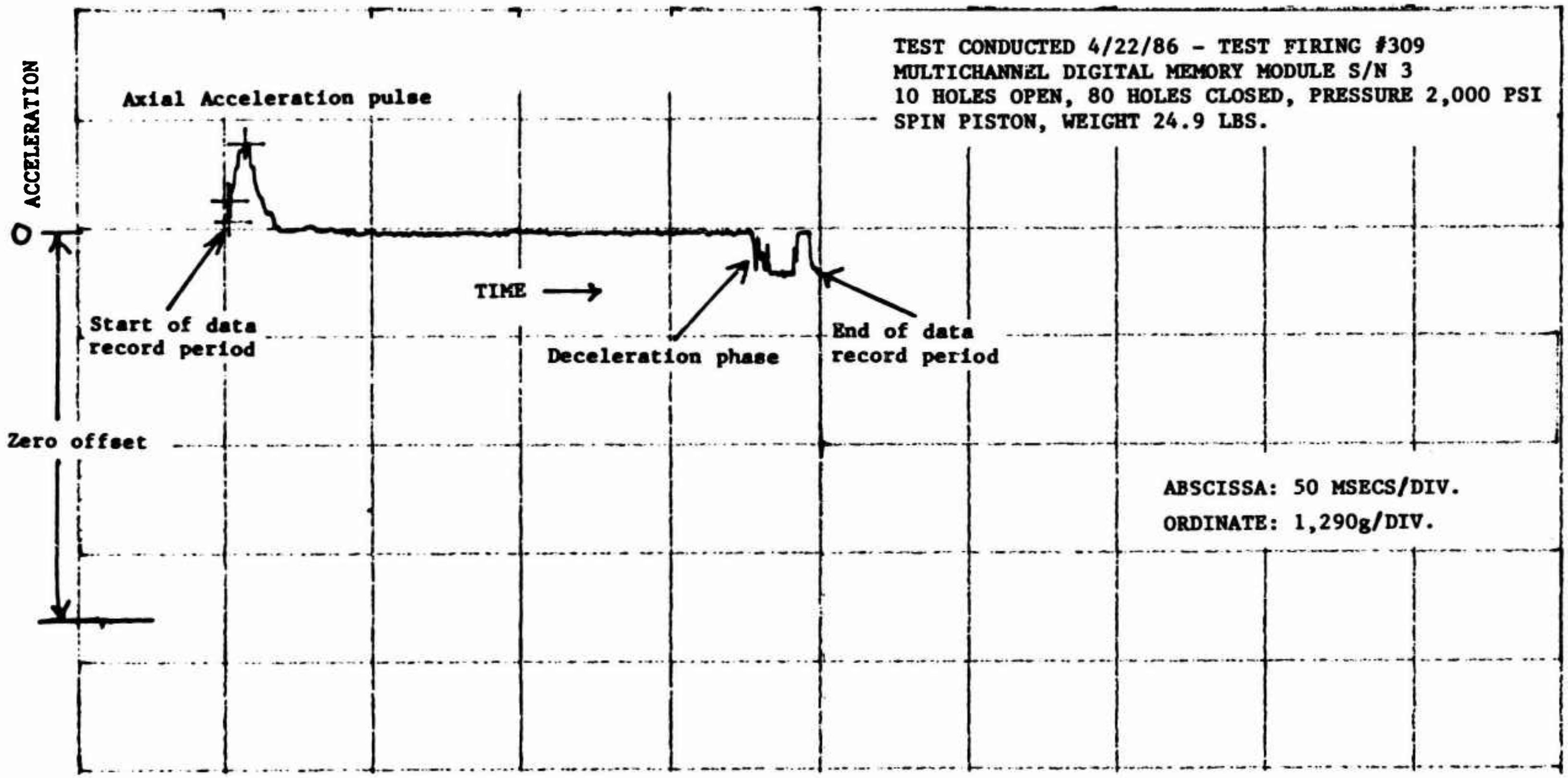

Figure 29. Axial acceleration, multichannel DMM, spin piston, firing 309, 50 msec per div.

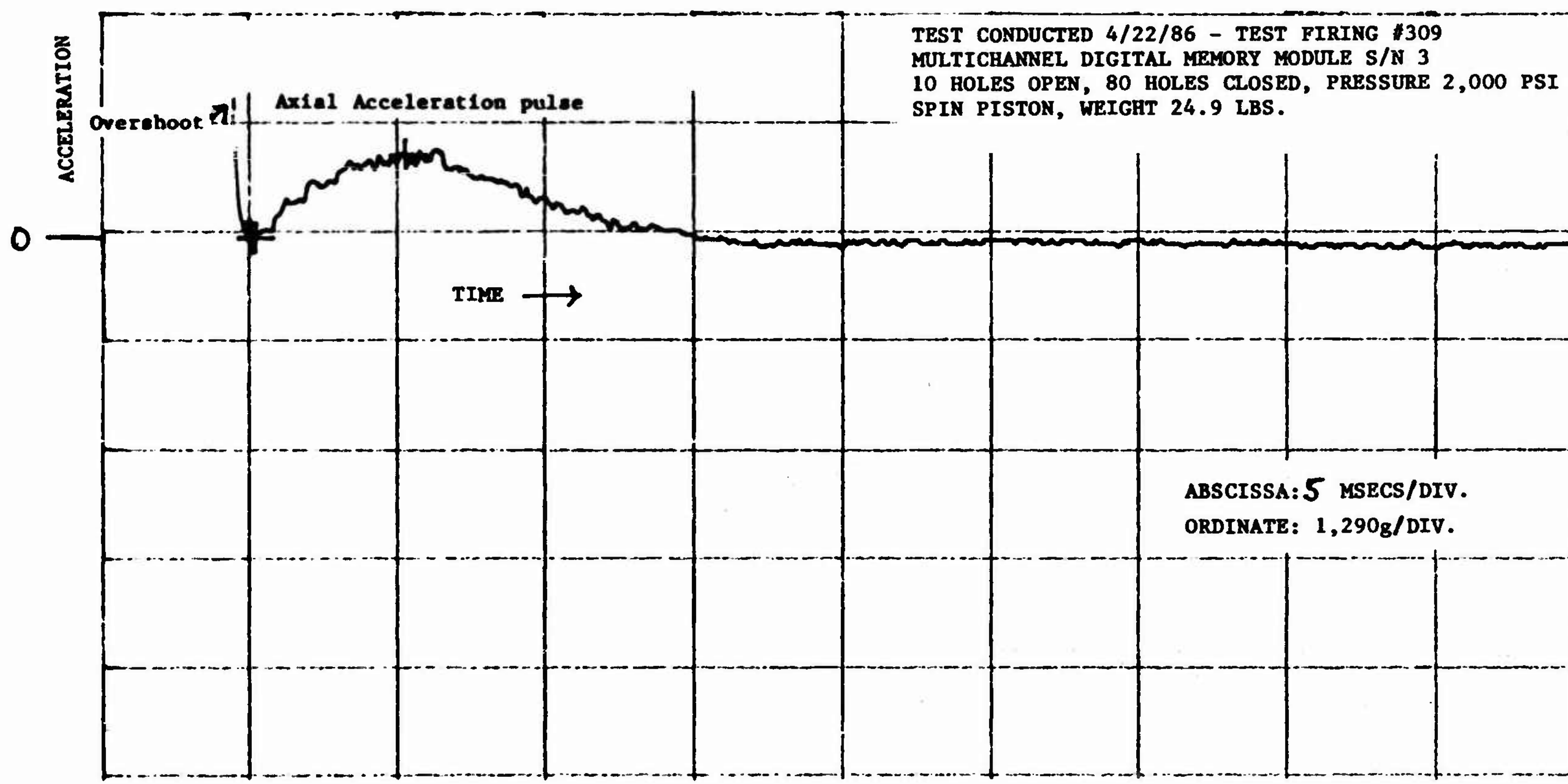

Figure 30. Axial acceleration, multichannel DMM, spin piston, firing 309, 5 msec per div.

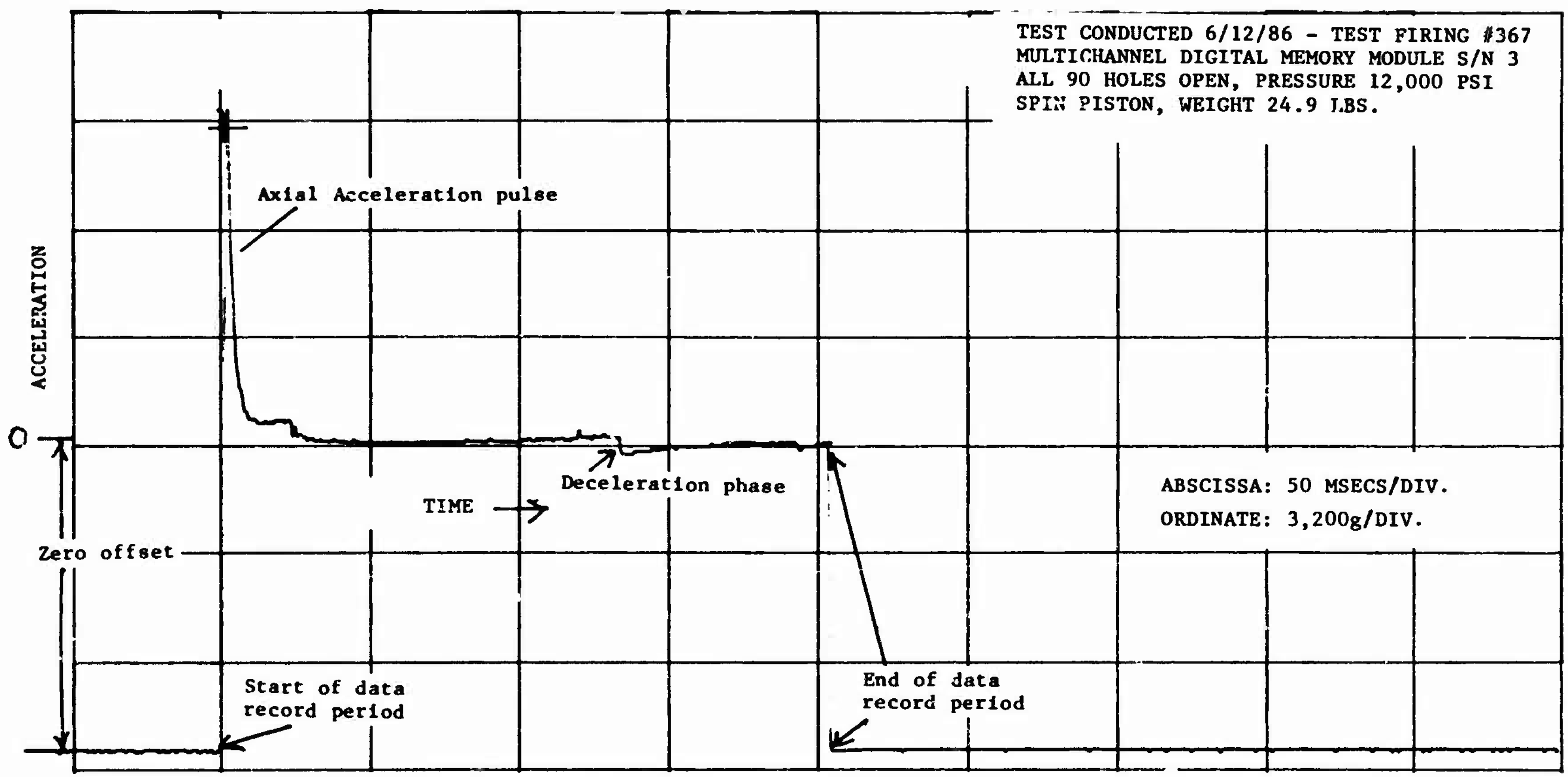

Figure 31. Axial acceleration, multichannel DMM, spin piston, firing 367, 50 msec per div.

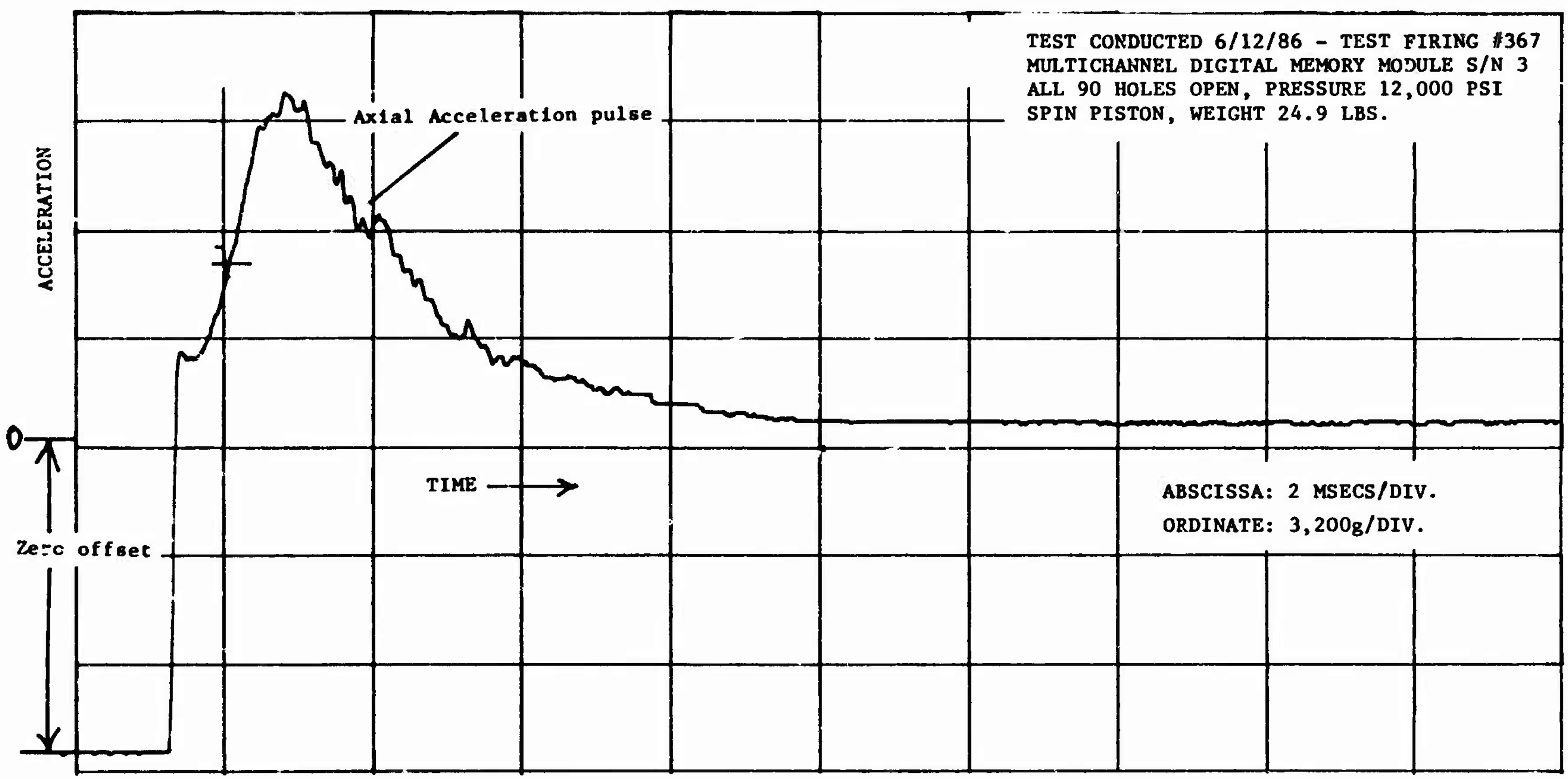

Figure 32. Axial acceleration, multichannel DMM, spin piston, firing 367, 2 msec per div.

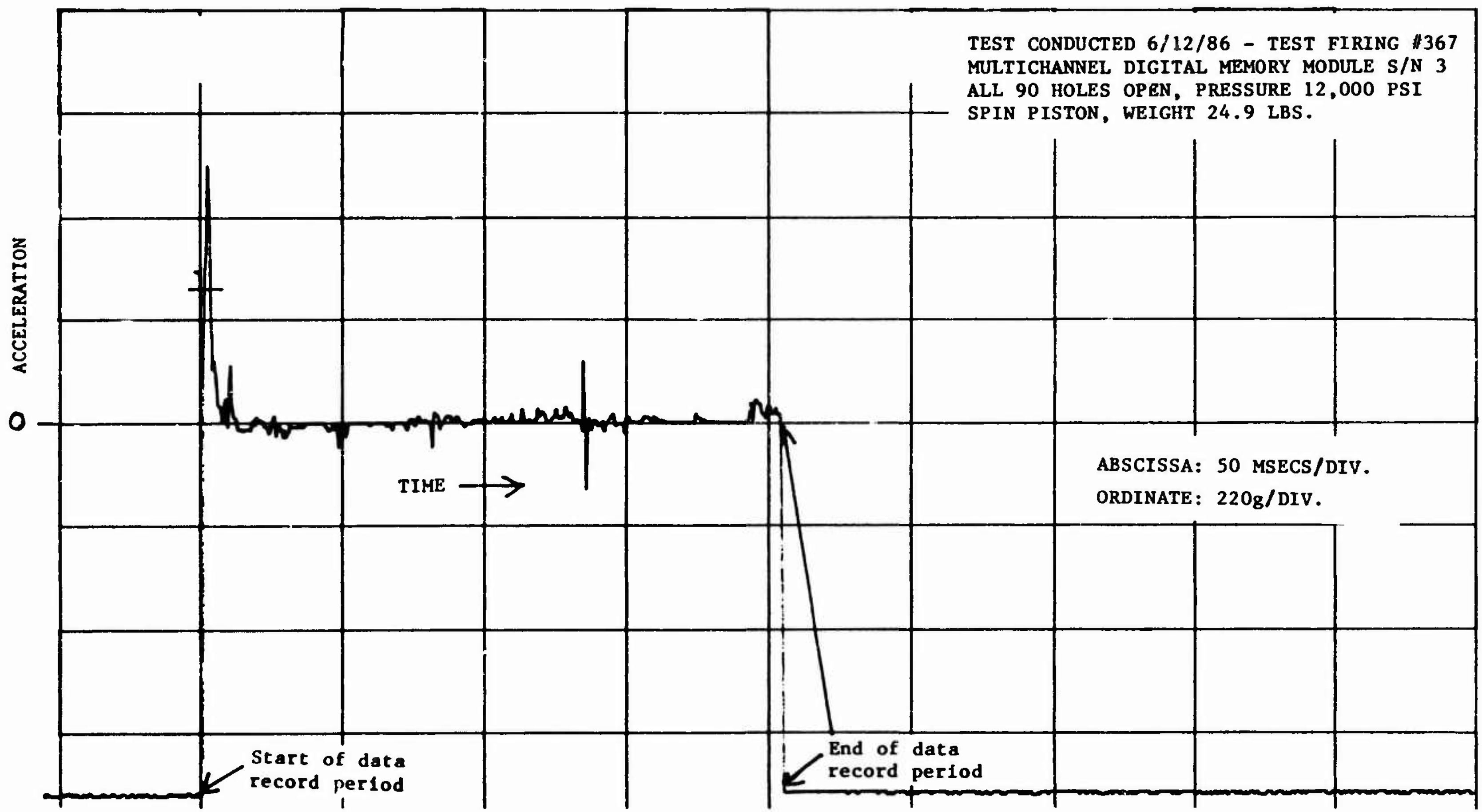

Figure 33. Tangential acceleration, multichannel DMM, spin piston, firing 367, 50 msec per div.

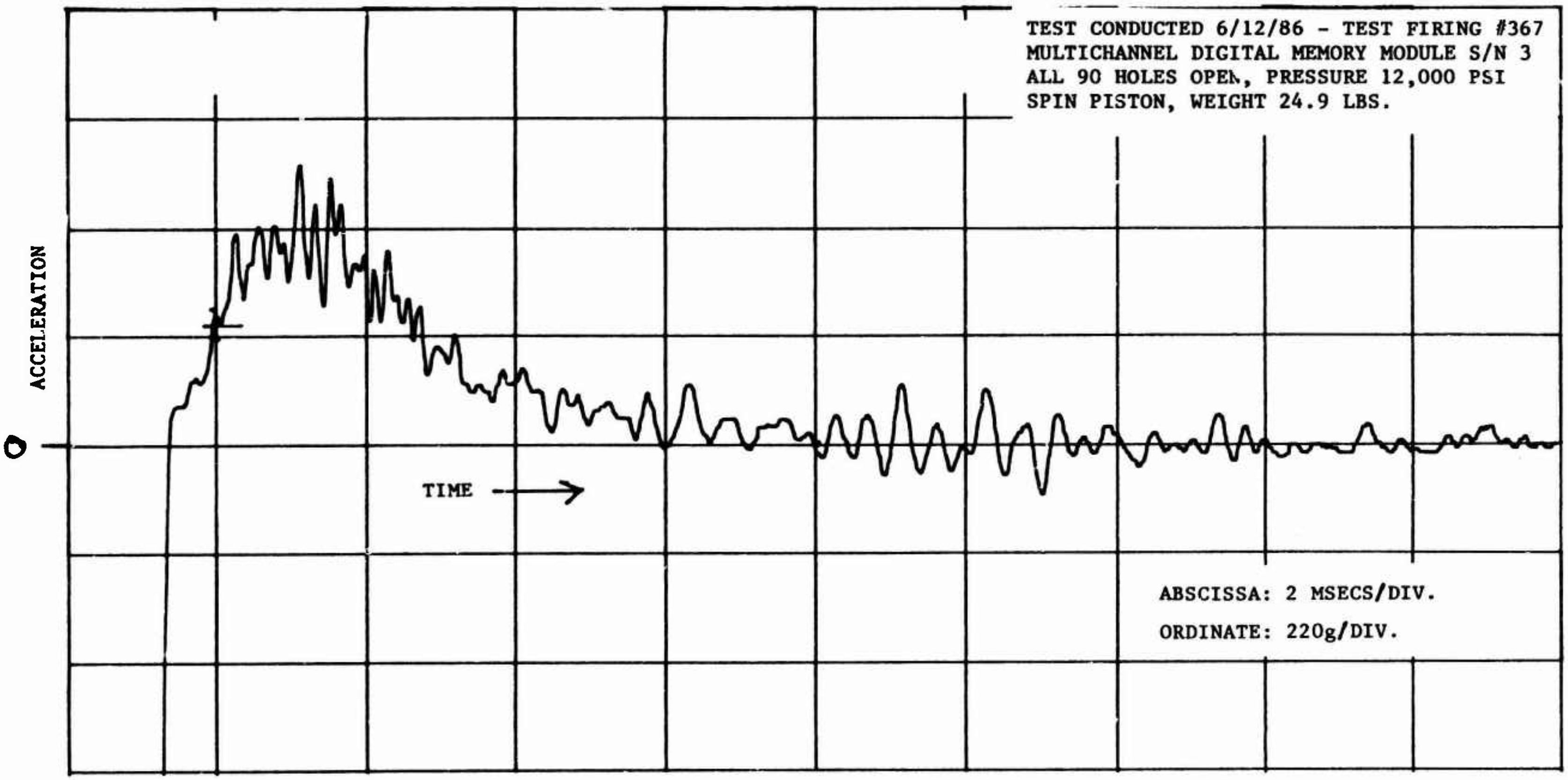

Figure 34. Tangential acceleration, multichannel DMM, spin piston, firing 367, 2 msec per div.

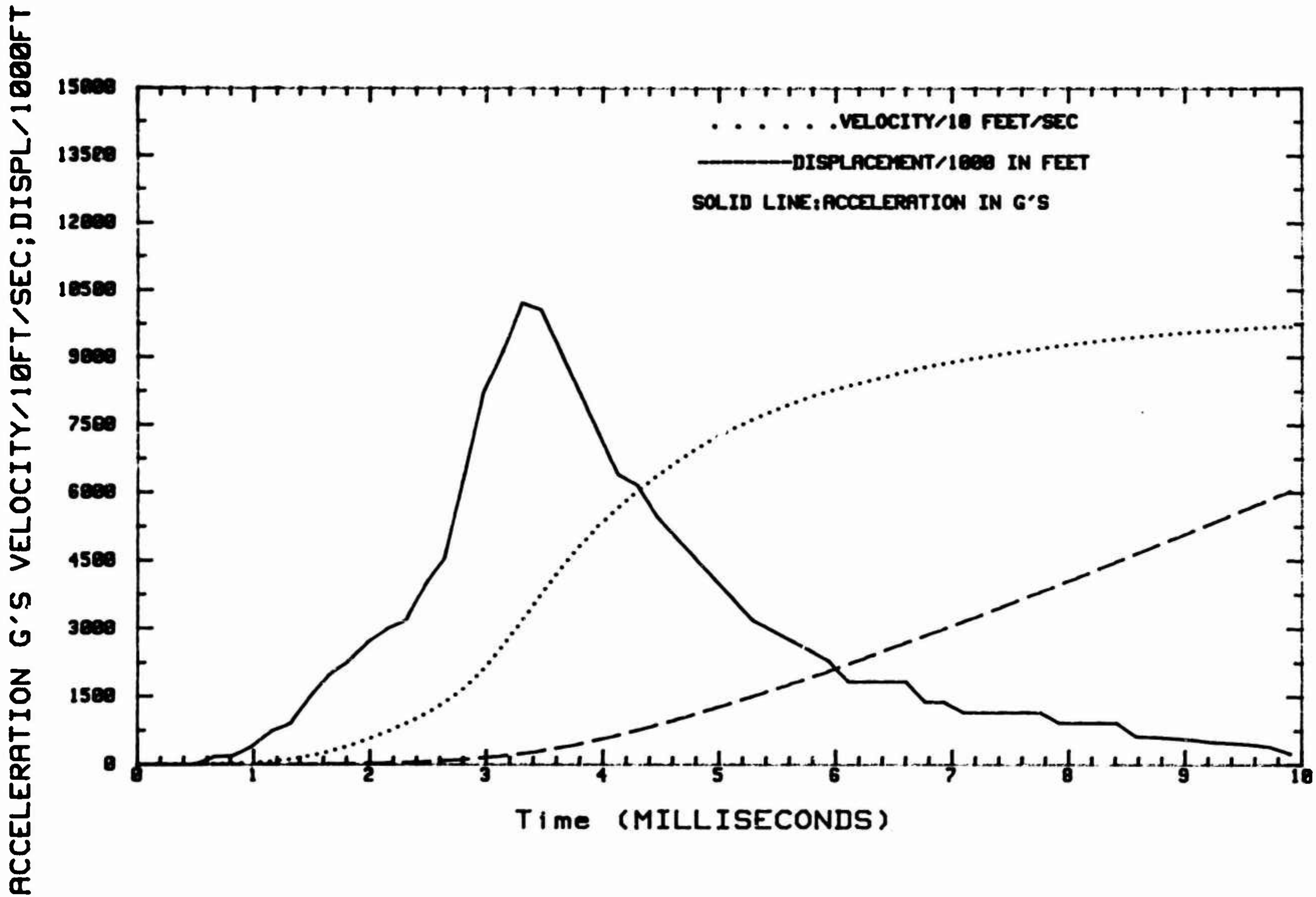

Figure 35. Integration of acceleration pulse, firing 302

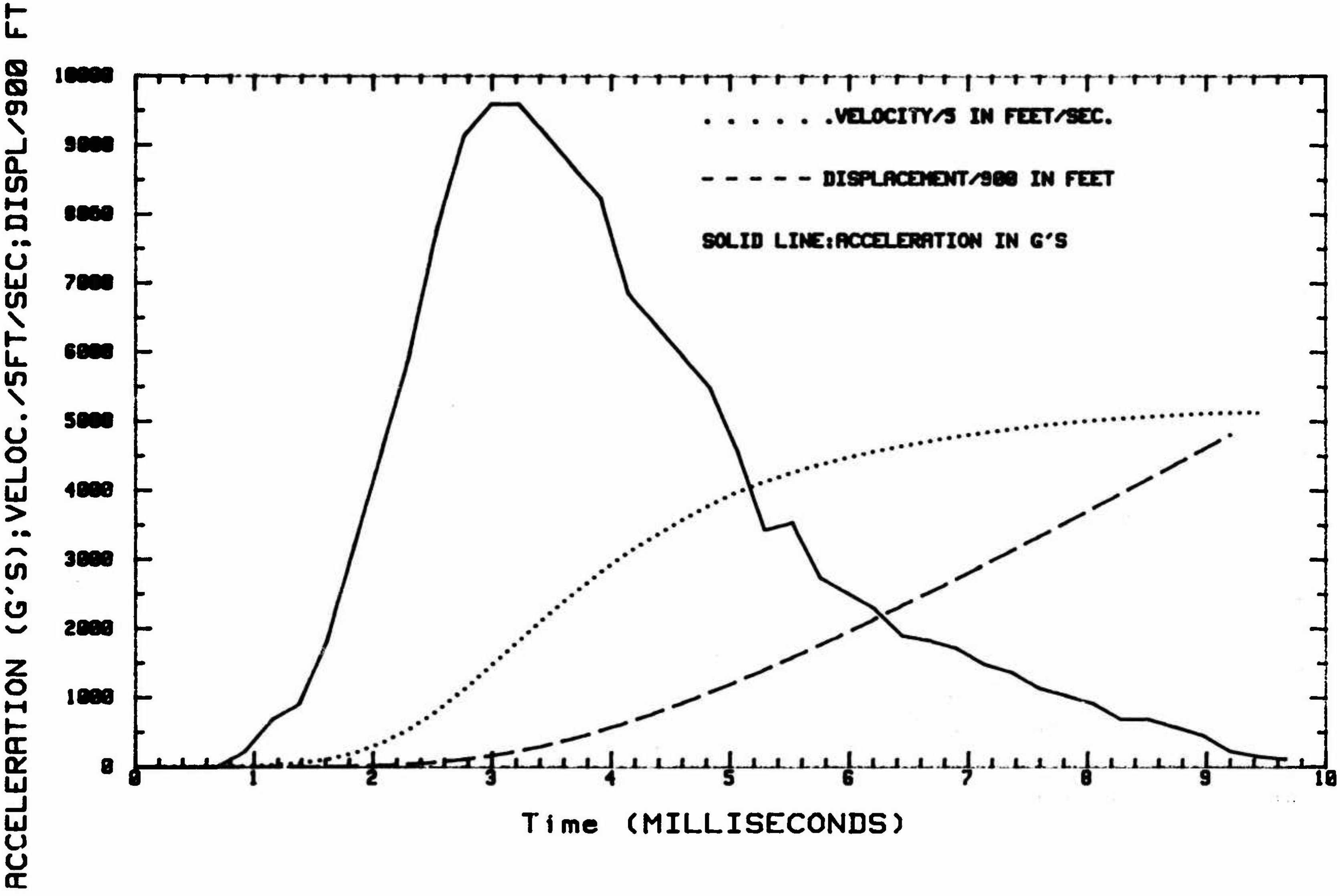

Figure 36. Integration of acceleration pulse, firing 303

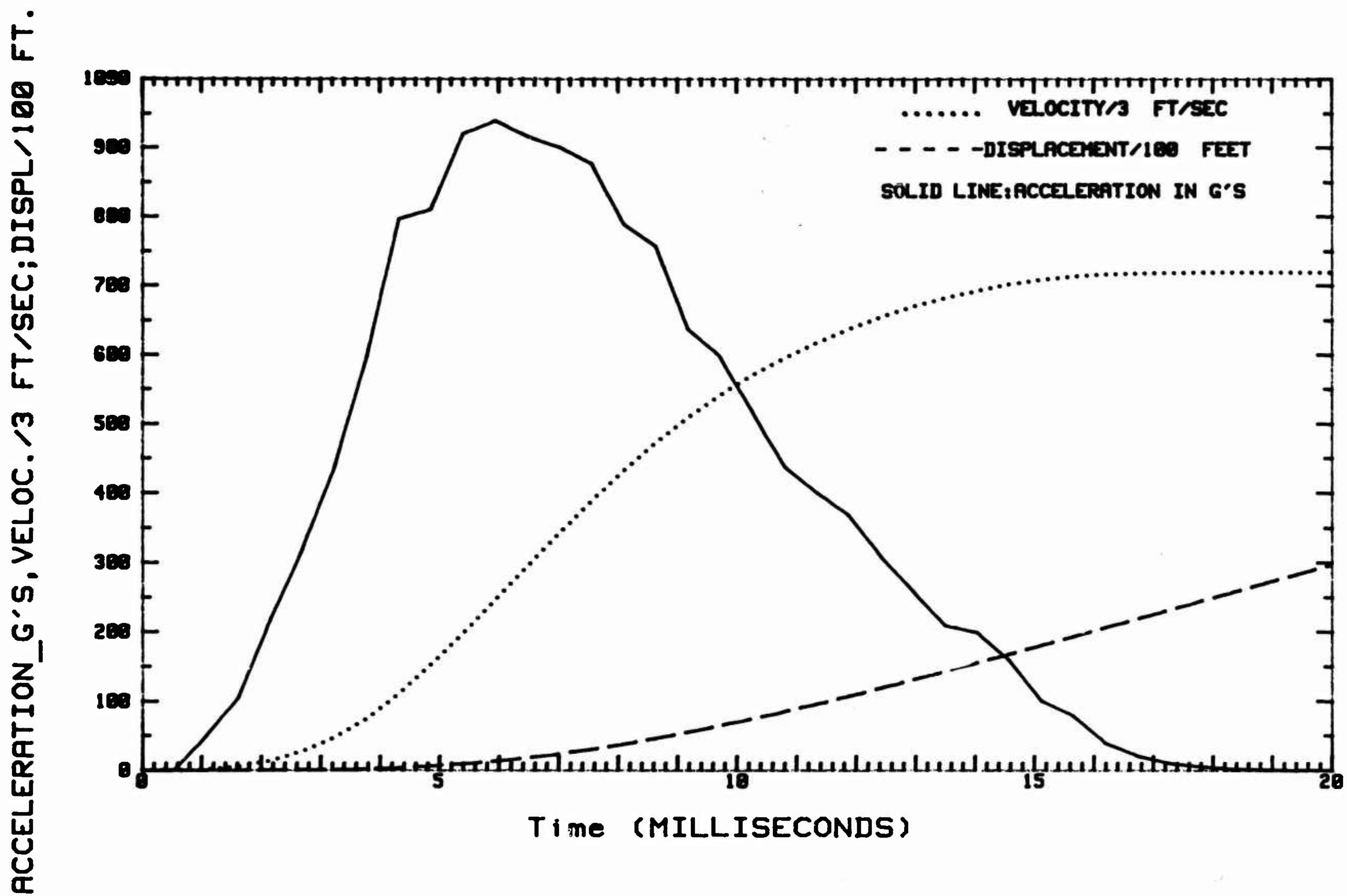

Figure 37. Integration of acceleration pulse, firing 309

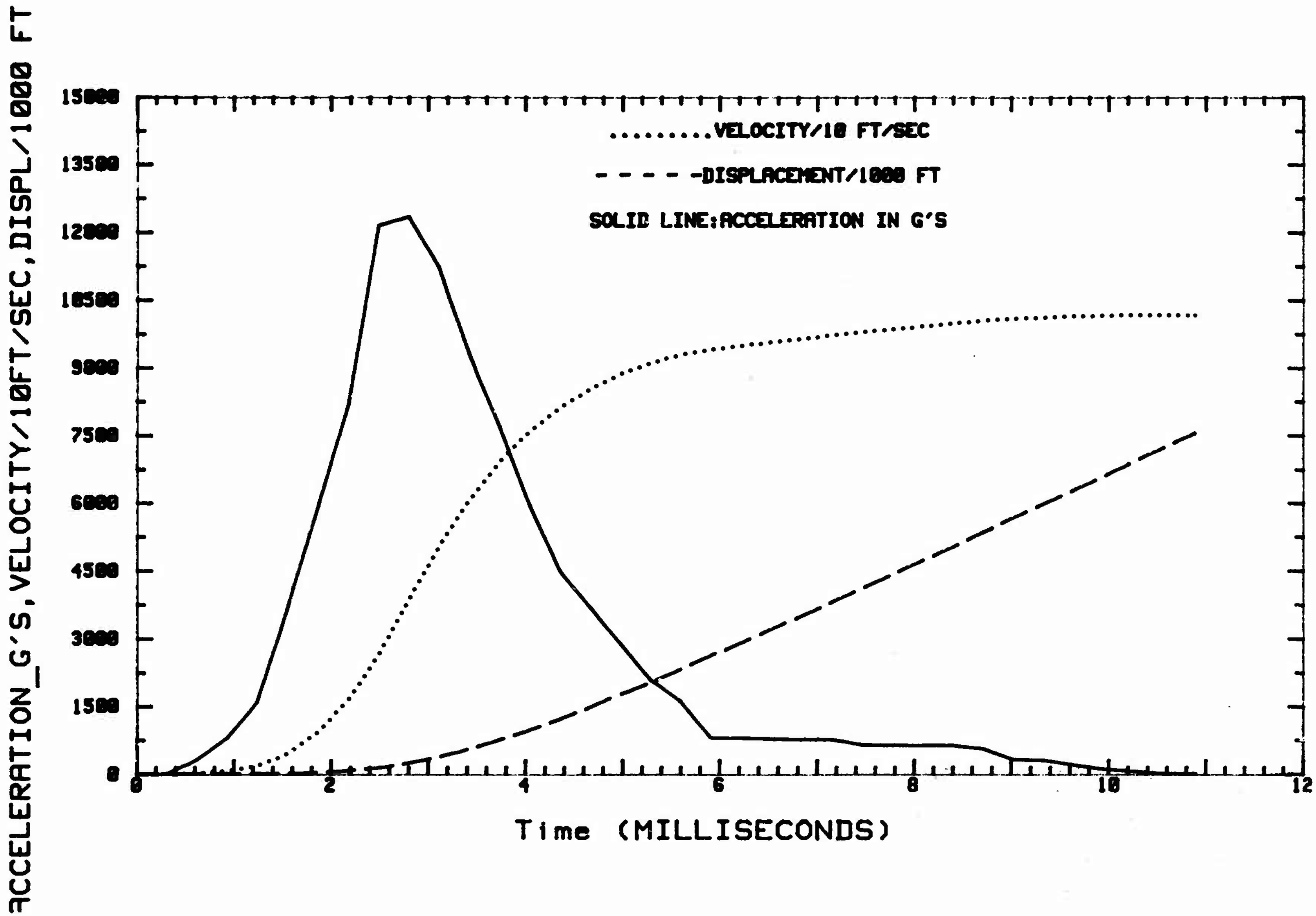

Figure 38. Integration of acceleration pulse, firing 321

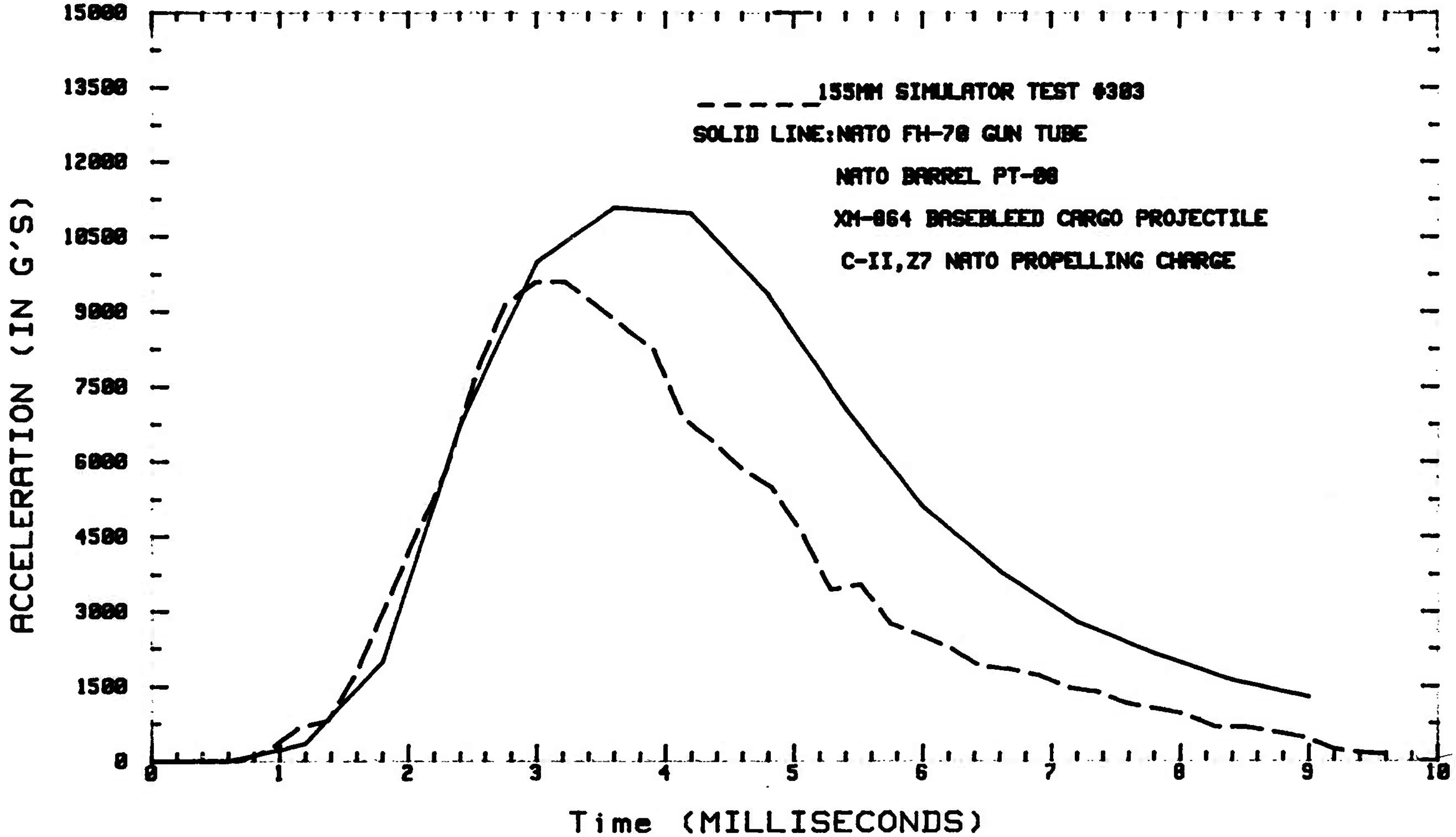

Figure 39. Gun firing and simulator acceleration time curves

DISTRIBUTION LIST

Commander
Armament Research, Development and
Engineering Center
U.S. Army Armament, Munitions
and Chemical Command
ATTN: SMCAR-AE
SMCAR-AE, Assoc. for Technology
SMCAR-AEB
SMCAR-AEC
SMCAR-AEC-E
SMCAR-AEC-EP, L. Szabo
SMCAR-AEC-T
SMCAR-AEC-TE
SMCAR-AEC-TEE, A. Karlsen (5)
SMCAR-AEF
SMCAR-AES
SMCAR-AET
SMCAR-CC
SMCAR-CC, Assoc. for Technology
SMCAR-CC, Assoc. for Engineering
SMCAR-CCB
SMCAR-CCH
SMCAR-CCL
SMCAR-CCS
SMCAR-ES
SMCAR-ESD(D)
SMCAR-FS
SMCAR-FS, Assoc. for Technology
SMCAR-FS, Assoc. for Engineering
SMCAR-FSA
SMCAR-FSF
SMCAR-FSM
SMCAR-FSN
SMCAR-FSP
SMCAR-FSS
SMCAR-TD
SMCAR-MSI (5)
Dover, NJ 07801-5001

Commander
U.S. Army Armament, Munitions
and Chemical Command
ATTN: AMSMC-GCL(D)
AMSMC-QA(D)
AMSMC-QAA(D)
AMSMC-QAH(D)
AMSMC-QAI
AMSMC-QAU(D)
Dover, NJ 07801-5001

PRECEDING PAGE BLANK

Commander
U.S. Army Test and Evaluation Command
ATTN: AMSTE-TE
Aberdeen Proving Ground, MD 21005-5066

Project Manager
Cannon Artillery Weapons Systems
ATTN: CAWS(D)
Dover, NJ 07801-5001

Project Manager
Mines, Countermine, and
Demolitions
ATTN: AMCPM-MCD(D)
Dover, NJ 07801-5001

Project Manager
Mortar Systems
ATTN: AMCPM-MO(D)
Dover, NJ 07801-5001

Project Manager
Tank Main Armament Systems
ATTN: AMCPM-TMA(D)
Dover, NJ 07801-5001

Office of the Project Manager
for Fuzes
ATTN: AMCPM-FM
Dover, NJ 07801-5001

Project Manager
Nuclear Munitions
ATTN: AMCPM-NUC
Dover, NJ 07801-5001

Administrator
Defense Technical Information Center
ATTN: Accessions Division (12)
Cameron Station
Alexandria, VA 22304-6145

Director
U.S. Army Materiel Systems
Analysis Activity
ATTN: AMXSY-MP
Aberdeen Proving Ground, MD 21005-5066

Commander
Chemical Research and Development Center
U.S. Army Armament, Munitions
and Chemical Command
ATTN: SMCCR-SPS-IL
Aberdeen Proving Ground, MD 21010-5423

Commander
Chemical Research and Development Center
U.S. Army Armament, Munitions
and Chemical Command
ATTN: SMCCR-RSP-A
Aberdeen Proving Ground, MD 21010-5423

Director
Ballistic Research Laboratory
ATTN: AMXBR-OD-ST
Aberdeen Proving Ground, MD 21005-5066

Chief
Benet Weapons Laboratory, CCAC
Armament Research and Development Center
U.S. Army Armament, Munitions
and Chemical Command
ATTN: SMCAR-CCB-TL
Watervliet, NY 12189-5000

Commander
U.S. Army Armament, Munitions
and Chemical Command
ATTN: SMCAR-ES
SMCAR-ESP-L
AMSMC-QA
AMSMC-QAI
AMSMC-RT, R. Radkiewicz
Rock Island, IL 61299-6000

Director
U.S. Army Materials Technology Laboratory
ATTN: SLCMT-MSI-QA
Watertown, MA 02172

Commander
NAVWPMCEN
ATTN: Code 01
China Lake, CA 93556-6001